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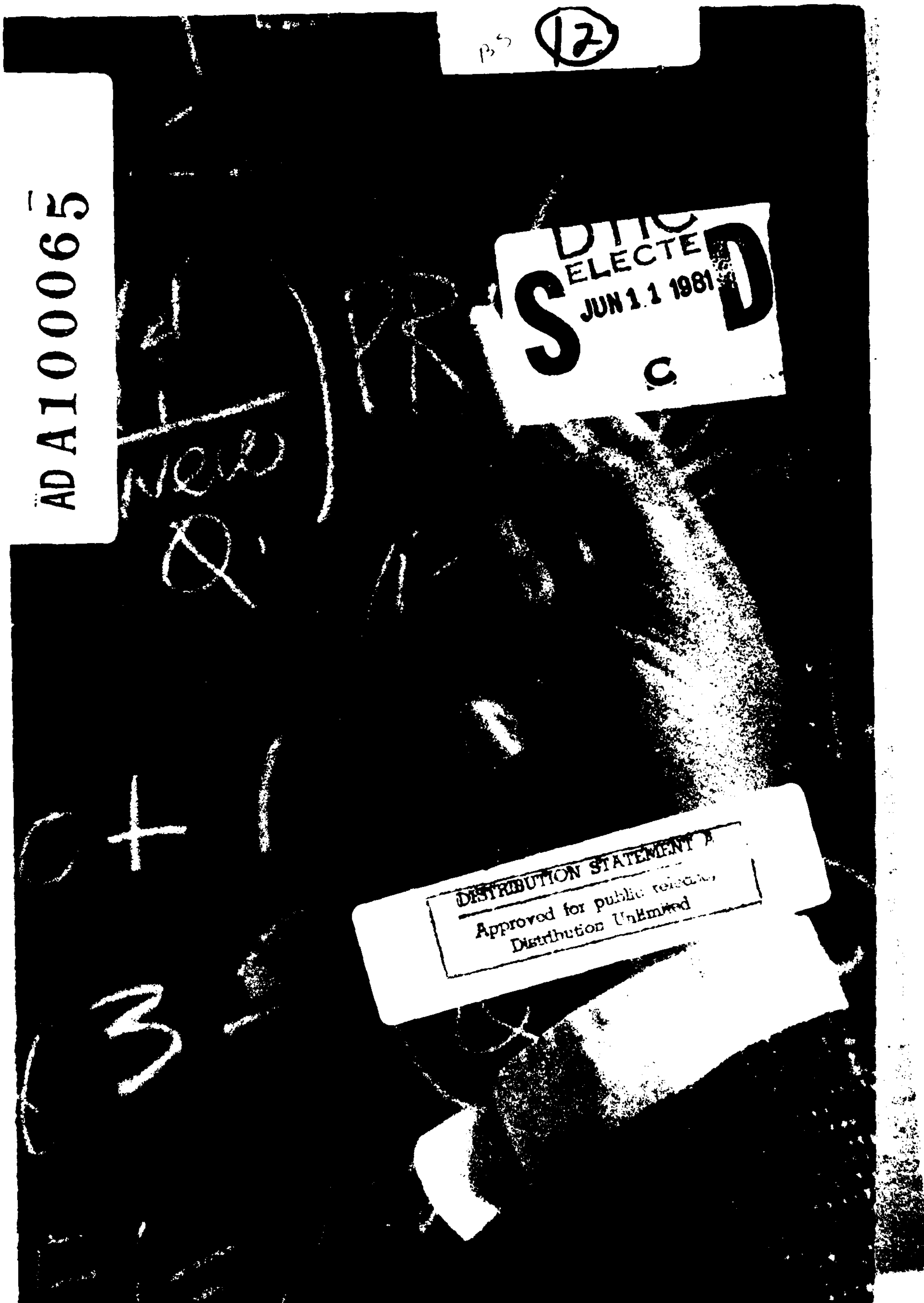

Concepts (formerly the *Defense Systems Management Review*) (USPS 526-630) is published quarterly by the Defense Systems Management College, Fort Belvoir, Va. 22060, and is intended to be a vehicle for the transmission of information on policies, trends, events, and current thinking affecting program management and defense systems acquisition.

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POSTMASTER: Send address changes to Editor, *Concepts*, Defense Systems Management College, Fort Belvoir, Va. 22060.

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Concepts

The Journal of
Defense Systems
Acquisition Management.

~~Spring 1981~~
Volume 4
Number 2

Spring 1981.
Volume 4.
Number 2.

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Special
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Cost Analysis

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Concepts

The Journal of
Defense Systems
Acquisition Management

Spring 1981
Volume 4
Number 2

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from the editor . . .

Ask anyone involved in the development and acquisition of military systems to list the major issues in that business, and you will find cost at or near the top. Hardly any decision is made in a development program without some consideration being given to cost, whether it be cost to develop, cost to buy, cost to support, or cost to maintain. Unless those cost questions are answered adequately, the program is in trouble.

The significance of cost in the acquisition process prompted many of our readers to call or write suggesting that we publish more material on cost analysis and cost estimating. That was the origin of the idea for a special cost analysis issue of *Concepts*, the fruit of which you now hold in your hands. Our objective is twofold. First, we want to provide useful information to those people actually charged with cost analysis responsibilities. Second, we want to provide insight into the workings of the cost analysis discipline for those who, though not cost analysts themselves, must depend to a great extent on the results of the cost analyst's work.

We of the editorial staff of *Concepts* want to express our appreciation for the invaluable assistance provided us by the OSD Cost Analysis Improvement Group, without which this project would never have come to fruition. We are particularly indebted to Mrs. Geri Asher, who worked with us from the very beginning of the project to help generate material, and then to provide what turned out to be a great deal of follow-up work. The guidance and support given us by the CAIG and Mrs. Asher serve to point up the seriousness with which DOD approaches the issues of cost analysis and cost estimating.

Of interest to the cost analysis community is the recent news that an Institute of Cost Analysis is being formed to develop and implement a Cost Analyst Program for both government and private-sector cost analysts. The current concept is to have cost analyst standards published and achievement programs established. As with news of the establishment of any new professional development association related to acquisition management, we will provide more details in a future issue of DSMC's bimonthly newsletter *Program Manager*.

It is with a mixture of sadness and elation that we find ourselves forced to say goodbye to one of the mainstays of the publications staff. Susan Pollock has been the Editorial Assistant here since 1977 and has not only seen the Publications Directorate grow, she has been in large measure responsible for that growth. She provided much of the initiative, drive, and talent that it has taken to improve the quality of DSMC publications. Without her competent assistance, it would have been impossible for us to have come so far in such a short time. Unless we can quickly convince her that there's more to life than a higher salary and better opportunities for advancement (fat chance), this will be Susan's last issue of *Concepts*. To her, we wish the best for the future. As for us . . . it looks like a long, hot summer.

7 Improving Cost Estimating in the Department of Defense

Milton A. Margolis

The accuracy and realism of weapon systems cost estimates are prerequisites for the efficient functioning of the Defense Systems Acquisition Review Council (DSARC), an advisory body to the Secretary of Defense on all major defense systems acquisition programs and related policy. At each major program decision point, all aspects of a program are reviewed by the DSARC. Programs breaching established cost thresholds are cause for interim DSARCs. Accordingly, emphasis on improving service cost estimates continues to receive high DOD priority. Taking the lead in this effort, the OSD Cost Analysis Improvement Group (CAIG) exercises the dual functions of vigorously reviewing service cost estimates for the DSARC, and fostering defense-wide improvements in military cost analysis capabilities.

Cost Analysis Improvement Group

The CAIG is made up of representatives from the Under Secretary of Defense (Research and Engineering), and the Assistant Secretaries of Defense (Comptroller), (Manpower, Reserve Affairs, and Logistics), and (Program Analysis and Evaluation). Also represented are the military departments' cost analysis organizations and the Joint Chiefs of Staff (JCS).

The military departments are required to submit two program cost estimates at each DSARC decision point. One estimate is prepared by the relevant program office and the second by a separate organization within the military department, independent of the program office.

Fifteen working days prior to the convening of the DSARC, the military department presents these estimates to the CAIG. On the basis of this presentation and subsequent analysis, the CAIG prepares a memorandum for the DSARC with the CAIG evaluation of the estimates presented. Meeting with the DSARC principals, the CAIG Chairman summarizes the CAIG evaluation and responds to questions of the DSARC members. In supporting the CAIG review of the military department cost estimates, the CAIG members contribute in accordance with their particular expertise. The Office of the Secretary of Defense (Program Analysis and Evaluation) analysts generally coordinate overall analysis and the preparation of the independent CAIG estimate. The CAIG and military department independent assessments serve as a inducement to the program manager to estimate his program more accurately. They have even served from time to time as a basis for the program manager to revise his estimate. However, the program manager is held responsible for his program, and it is his estimates that are reflected in the DOD budget sent to the Congress.

Milton A. Margolis is Deputy Assistant Secretary, Resource Analysis, in the Office of the Assistant Secretary of Defense (Program Analysis and Evaluation). He is also Chairman of the OSD Cost Analysis Improvement Group. He served previously as the Director, Cost and Economic Analysis Directorate, OASD(PA&E). Mr. Margolis holds a B.A. degree from Columbia University.

TABLE I
Major Weapon Systems Acquisition Annual Rate of Cost Growth

Selected Acquisition Reports (SARs) As of Date	Annual Growth Rate
December 1972*	6.4%
June 1974*	5.2%
March 1975*	4.4%
March 1975	3.7%
March 1976	3.0%
December 1977	3.3%
December 1978	3.6%
March 1979	3.4%
September 1980	3.7%
December 1980	3.9%

*Based on development estimates which included anticipated inflation; other rates are based totally on base year dollars.

Cost Growth in SARs

Cost growth reported in the selected acquisition reports (SARs) is some indication of the success of CAIG activities. Our examination of SARs (see Table I) indicates that after adjustment for quantity change and inflation, DOD showed substantial improvement in controlling cost growth during the early '70s when the overall annual cost growth rate dropped from over 6 percent down to 3.7 percent. Since 1975, the rate has been maintained between 3.0 percent and 3.7 percent. In this last year, however, we have seen cost growth begin to creep up again. The December 1980 SARs show annual rate of cost growth for DOD as a whole of 3.9 percent. Cost growth is measured relative to the development estimate made at the time a weapon system passes the DSARC II milestone and enters full-scale development.

Our analysis of these SAR reports also shows that, in reviewing the total cost growth experienced, unanticipated inflation was the single major factor contributing to cost growth in DOD's weapon acquisitions. During the 1975–80 time period, unanticipated inflation varied between 70 percent and 78 percent of total cost growth (see Table II). Of this total unanticipated inflation, the escalation associated with the program as originally conceived remained rather constant, around $25 billion, until 1979; since then it has just about doubled with the F-18, F-16, *Trident*, XM-1, and CG-47 accounting for $11 billion of the increase. The escalation associated with program changes grew from $11 billion in March 1975 to $84.6 billion in December 1980. Much of this increase was due to the inflation associated with the significant increases in quantities in the F-18, F-16, Trident,

TABLE II
Cost Growth Due to Unanticipated Escalation in Selected Acquisition Reports (SARs)

	Dollars in Billions				
	March 75	March 76	December 77	March 79	December 80
Number of Programs	(50)	(52)	(56)	(58)	(55)
Development Estimate (Base Yr $)	92.3	97.1	104.0	103.8	101.4
Projected Inflation	13.0	19.2	26.1	34.3	36.8
Total Development Estimate	105.3	116.2	130.1	138.1	138.2
Current Estimate (Base Yr $)	102.9	109.7	123.2	132.9	148.4
Actual plus Projected Inflation	48.9	64.4	87.1	102.2	169.6
Total Current Estimate	151.8	174.1	210.3	235.1	318.0
Total Cost Growth	46.5	57.9	80.2	97.0	179.8
Cost Growth as Percent of Total Development Estimate	44%	50%	62%	70%	130%
Cost Growth Due to Unanticipated Inflation:					
Related to Program Changes	11.0	16.4	37.8	43.7	84.6
Related to Original Program	24.9	28.8	23.2	24.2	48.2
Total Unanticipated Inflation	35.9	45.2	61.0	67.9	132.8
Unanticipated Inflation as a Percent of Total Cost Growth	77%	78%	76%	70%	74%

and XM-1 programs. Both unanticipated inflation and changes in program quantities are aspects of a program over which cost analysts and program managers have very little, if any, control.

Table III provides a breakout of all factors of cost growth as estimated by the program offices for the SAR programs. Although none of the other factors of cost growth have contributed to a substantial share of the growth, in the aggregate, these factors have become more significant over the last few years. Note that program offices attribute no more than 6 percent of the total cost growth to estimating errors.

The best and fairest way to measure "real" cost growth is to adjust the development estimate for both escalation and quantity changes in calculating the cost-growth ratio. By doing so, we have eliminated those factors beyond the control of the program manager and are comparing the original and current estimates of the program for the currently planned production quantities. Table IV shows this adjustment for the 1975–80 time period. The "real" cost growth appears to have remained relatively stable at about 15 percent from 1975 to early 1979, but since then has jumped to 25 percent.

The SAR is not a perfect reporting system. It is essentially unaudited. Considerable flexibility in classifying the sources of growth is allowed. We have to accept the fact that it is a temptation for program managers to assign changes in their costs to factors beyond their control, i.e. inflation. It is a convenient way to avoid acknowledging real cost growth. Inflation can, in a real sense, undermine the DSARC's attempts to set and hold to fiscal constraints on individual acquisition programs.

In short, SAR data is only a general indicator of weapon system cost status. Although overshadowed by the impact of inflation, improvements appeared to have been made in the early '70s, and was stabilized during the mid-'70s; it now appears to be starting upward again. Clearly, we need to continue to drive for better cost data, more realistic cost estimates, and better cost management. The CAIG's role in this effort is described below.

DOD Directive 5000.4

The existence of the CAIG was formalized in June 1973 with the issuance of DOD Directive 5000.4, the organization's charter. It was reissued on October 30, 1980, with changes consistent with the revised March 19, 1980, DOD Directive 5000.1, "Major Systems Acquisitions," and DOD Instruction 5000.2," Major System Acquisitions Procedures." The "Criteria and Procedures for the Preparation and Presentation of Cost Analyses to the OSD CAIG" was added as an enclosure. The DOD Directive 5000.4 outlines the membership of the CAIG and delineates specific responsibilities that can be summarized as follows: performing independent cost reviews in support of DSARCs; providing criteria and procedures for these reviews; establishing DOD's cost analysis policies and

TABLE III
Cost Growth in Selected Acquisition Reports (SARs)

	(Dollars in Billions)									
	March 75		March 76		December 77		March 79		December 80	
	Dollars	Percent	Dollars	Percent	Dollars	Percent	Dollars	Percent	Dollars	Percent
Number of Programs	(50)		(52)		(56)		(58)		(55)	
Escalation	35.9	77	45.2	78	61.0	76	67.9	70	132.8	74
Quantity	(1.7)	(3)	1.4	2	1.4	2	11.4	12	16.9	9
Schedule	4.6	10	4.4	8	5.9	7	5.1	5	6.9	4
Engineering	4.2	9	2.8	5	4.2	5	2.8	3	4.5	3
Support	1.2	2	.6	1	2.9	4	3.2	3	5.4	3
Estimating	.1	-	1.2	2	3.1	4	4.4	5	11.5	6
Other	2.2	5	2.3	4	1.7	2	2.2	2	1.7	1
Total Cost Growth	46.5	100	57.9	100	80.2	100	97.0	100	179.8	100

TABLE IV

Cost Growth after Adjustment for Quantity and Escalation (Dollars in Billions)

	March 75	March 76	December 77	March 79	December 80
Number of SAR Programs	(50)	(52)	(56)	(58)	(55)
Development Estimate (Current $)	105.3	116.2	130.1	138.1	138.3
Quantity Changes (Current $)	.4	5.5	16.6	32.5	30.4
Total Development Estimate Adjusted for Quantity	105.7	121.7	146.7	170.6	168.7
Current Estimate (Current $)	151.8	174.1	210.3	235.1	318.0
Cost Growth Adjusted for Quantity	44%	43%	43%	38%	88%
Development Estimate (Base Yr $)	92.3	97.1	104.0	103.8	101.4
Quantity Changes (Base Yr $)	(1.7)	1.4	1.4	11.4	16.9
Total Development Estimate Adjusted for Quantity and Escalation	90.6	98.5	105.4	115.2	118.3
Current Estimate (Base Yr $)	102.9	109.7	123.2	132.9	148.4
Cost Growth Adjusted for Quantity and Escalation	14%	11%	17%	15%	25%

guidelines; and integrating DOD's cost research program and cost data collection, storage, and exchange.

The "independent" cost estimate has been given attention throughout DOD since the establishment of the CAIG. It has been used to describe a cost analysis prepared by a separate organization and employing techniques different from those used by the program manager in making his estimate of weapon system cost. The CAIG has reviewed many military service estimates of varying quality and independence. While it is not possible to claim a perfect correlation between the two, in our experience the less independent the service estimate, the less it represents a valid check on the program manager's numbers.

For example, in those cases where both the program office and service independent estimates were prepared by the same people, there is a strong adherence to the same basic assumptions and a seeming effort to corroborate rather than to actually test the base estimate. Experience has shown that independence is an essential requirement if future cost reviews are to be of value to the DSARC.

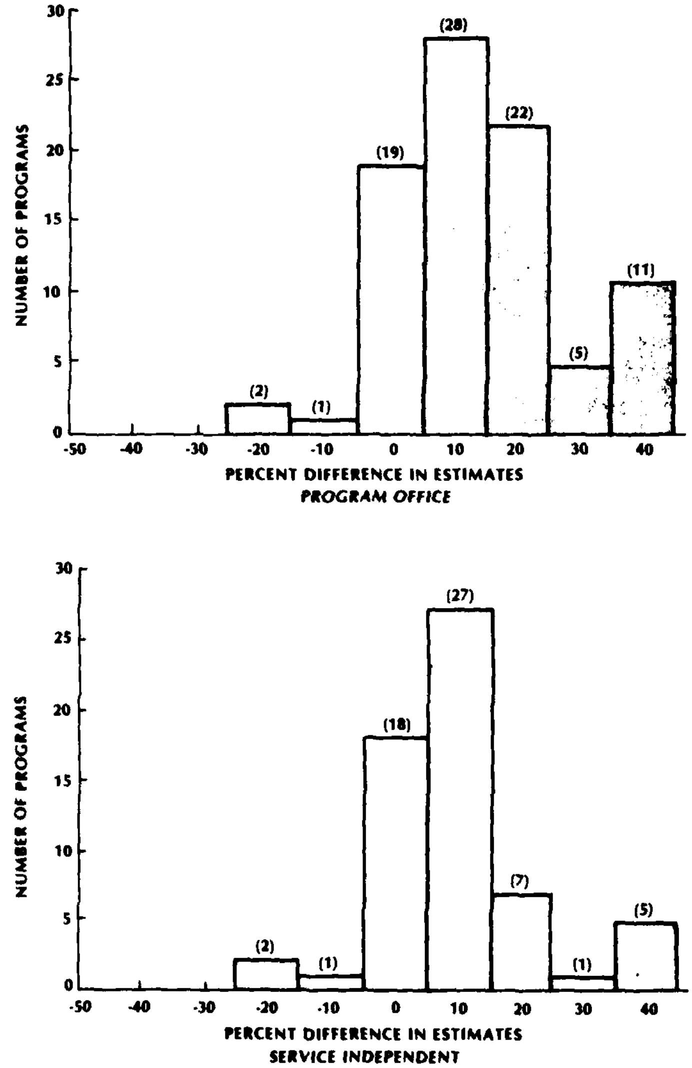
The CAIG has participated in over 150 DSARC reviews since 1972. In 88 of these reviews the CAIG has prepared its own independent cost estimates. These have not necessarily been totally derived cost estimates; in many cases they reflect adjustments for disagreements with the service estimate over the cost of specific components or subsystems, assumptions made, analytical techniques used, or assessment of cost risk. In about 25 percent of these reviews the CAIG has agreed with the service independent estimate, which ranged from 20 percent below to 35 percent above the program office estimates. Figure 1 presents a comparison of the ratio between the CAIG and program office estimates, and the CAIG and the independent cost estimates.

These ratios over the 8 years the CAIG has been in existence have remained fairly constant. Both distributions are skewed to the right; that is, the CAIG's estimates have tended to be higher than either the program office or the service independent estimates, and on the whole agree more closely with the latter. The CAIG and service independent estimates are generally based on techniques that rely heavily on actual costs of similar prior programs that have experienced the normal delays, problems, mistakes, and redirection in their development. The program manager projections are generally a product of industrial engineering judgments made by the contractors involved with the program, who are naturally in an advocacy role.

In a number of cases where CAIG has differed significantly from the program manager, the DSARC has requested that further, more comprehensive analyses be performed. For example, in the case of the Harpoon anti-ship cruise missile, the CAIG report of June 24, 1974, projected the total planned production missiles

FIGURE 1

Comparison of CAIG Estimates to Program Office and Service Independent Estimates for Weapon System Procurement Costs (1972–1980)



would run 20 percent higher than the program manager's estimate. It also identified a shortfall in the FY75 funds budgeted for the Harpoon pilot production. The DSARC Chairman requested the program manager, working with the Navy independent estimating group and the CAIG, "to more fully assess projected cost growth and its impact on later year procurement." That study, completed in November 1974, indicated that procurement costs were underestimated by more than 50 percent, and resulted in the program manager revising his program costs upward by about 40 percent. To stay within his FY75 budget, the program manager also had to shift the completion of 50 of the 150 missiles in FY75 into the FY76 budget. The CAIG forced the cost issue into the open and there was an admision by all parties that the program was underfunded.

Another example of the CAIG analysis that significantly affected OSD decision-making, was a cost comparison of the Pratt and Whitney F100 and the General Electric F101-DFE aircraft engines. For several years, the F100 engine installed on the F-15 and F-16 fighter aircraft experienced serious reliability problems. Although significant progress was made, at great expense, to correct these problems, the Air Force in 1979 asked General Electric to develop a possible substitute engine. GE proposed the F101-DFE, a derivative of an engine originally developed for the B-1 bomber. The F101-DFE, although heavier than the F100, contains fewer parts and was recommended by GE as a more durable engine that would be less expensive to operate.

When the Air Force presented a proposal to substitute the F101-DFE for the F100 on the last 638 F-16s, the CAIG was asked to perform a comparative life-cycle-cost analysis of the two engines for the F-16. The CAIG found that although operating and support costs would be significantly lower on the F101-DFE, these savings, on a life-cycle basis, could not offset the much higher development and procurement costs associated with that engine. In fact, in FY 1981 dollars the additional life-cycle costs of the F101-DFE vs. the F100 engine would be over one-half billion dollars. When costs were discounted at the 10 percent rate, the additional costs were almost three-quarters of a billion dollars.

As a result of this study, OSD decided not to approve the substitution of the F101-DFE for the F100 on the F-16, but resources were included in the budget to continue the engine development for possible use on future weapon systems.

Another recent CAIG analysis that contributed to OSD decision-making was the review of the Navy's F-18 program. As part of the DSARC III Review, the acquisition executive established a DOD Review Group on June 30, 1980, to evaluate the technical, operational, and cost status of the F-18 program. This review was designed to provide the Secretary of Defense with the information necessary to make an F-18 production decision, and to permit him to respond to questions from the President and the Congress on the program.

Cost reports indicated that the Navy's current cost estimates for the F-18 program had almost doubled since the November 1975 DSARC II. The CAIG's evaluation presented to the DSARC in the late fall of 1980 showed that over two-thirds of the increase was caused by unexpected inflation, and the remaining one-third was due to configuration uncertainty, schedule changes, and underestimation of equipment costs. This CAIG cost analysis played an important role in the decision-making process on the future of the F-18 production program.

As mentioned above, an enclosure has been added to the reissued DOD Directive 5000.4, "OSD Cost Analysis Improvement Group," containing the "Criteria and Procedures for the Preparation and Presentation of Cost Analyses to the OSD CAIG." It addresses the objective of the CAIG presentations and organizational responsibilities. It describes the scope of the independent analysis, the preferred analytical methods to be used, and the content of the presentation of the cost results to the CAIG. It also establishes the procedures to be followed in preparing for a CAIG presentation. These criteria and procedures have evolved over the 8 years the CAIG has been in existence and represent the recommendations of the DOD cost-analysis community.

The preferred analytical techniques to be used in making independent cost estimates of R&D, investment, and operating and support costs depend on the stage of the acquisition cycle that the weapon system is in when the estimate is made. Until sufficient actual costs of R&D hardware are available, the CAIG encourages the use of the parametric costing techniques for the R&D and investment estimates. Cost estimates prepared for DSARCs I and II should be based on parametric, analog, and engineering techniques depending on the extent of data available. At DSARC III, projection from cost actuals should be the primary basis for the cost estimate. In all cases, the preferred approach is to use several cost-estimating methods to support the independent acquisition cost estimate.

For operating and support costs, much of our current data is still based on planning information rather than actual consumption. This presents many problems in developing detailed operating and support cost estimates. As VAMOSC becomes a viable reporting system, both operating and support costs and other associated data will become available, allowing the services to make better judgments of the correlation between operational concepts, design characteristics, reliability, maintainability, and so on, and their impact on costs. The CAIG-published *Aircraft Operating and Support, Cost Development Guide,* April 15, 1980, updates and expands the May 1974 guide. It is applicable to any operating and support cost analysis performed during the acquisition process, including cost effectiveness and trade-off studies. The guidance is directed at costs used in the acquisition program decisions and is not the same as one necessarily would use for total program costs or budget estimates. The guidance provided in this document will be expanded to other weapon classes, and is expected to be issued in the near future.

Progress to Date

The CAIG has been in existence for a little more than 8 years and in that time there have been substantial improvements made in the quality and credibility of cost estimates supplied to Congress. These improvements have been achieved through a variety of activities, among which the most important are:

—Requiring independent cost estimates from the military departments;

—Sponsoring contractor and in-house research studies aimed at improving cost estimating techniques;

—Collecting and processing a consistent, comparable data base for cost analysis purposes;

—Widening the dissemination of actual data usable for cost analysis;

—Developing the expertise and data base to deal with analysis of multinational acquisitions.

Although defense acquisition programs still exhibit constant-dollar cost growth, the ongoing CAIG effort has contributed substantially to reducing the average annual rate of cost growth prevalent in 1972. Continued emphasis on the present cost improvement program, along with new initiatives in the operating and support cost area to improve and give more visibility to life-cycle-cost estimates, is providing the opportunity for even more significant progress in defense weapon sytems cost estimating.

Foreword to Special Section

Estimating in the '80s

Dr. John D. Morgan
Director, Cost and Economic Analysis Directorate
Office of the Assistant Secretary of Defense (Program Analysis and Evaluation)

In the demanding business of defense systems acquisition, there is a critical and continuing need for the work of capable, creative professional cost analysts. The Department of Defense cost analyst is an essential player in support of such efforts as Defense Systems Acquisition Review Council (DSARC) reviews, force planning studies, and service budget preparation activities. Any neglect of the professional development of the defense cost analyst will have severe consequences for these and other functions that rely heavily on valid and readily available cost estimates.

For the past 15 years, the Department of Defense has sponsored annual cost analysis symposia to enhance the professional development of cost analysts and to promote more effective performance of the cost analysis function within DOD. These symposia are designed primarily for managers and practitioners of cost analysis throughout DOD and for members of the research organizations that support them. The symposia are devoted to such topics as the output of DOD and contract cost research studies; defense or national issues that have or could have a significant impact on defense cost analysis; and proposed or ongoing cost research programs.

The Fifteenth Annual Cost Analysis Symposium was held in October 1980. To help members of the cost analysis community prepare for future challenges, a general session meeting at that symposium was devoted to a panel discussion addressing "Estimating in the '80s." I was privileged to be a member of that panel, which had as its moderator Mr. Leroy T. Baseman, Chairman of the Air Force Cost Analysis Improvement Group. Joining me on that panel were Mr. Wayne Allen, Director of Cost Analysis, Office of the Comptroller of the Army; Mr. Riner Payne, then Deputy for Financial Systems and Analysis, Headquarters U.S. Air Force; Mr. Joseph T. Kammerer, Director of Cost Estimating, Headquarters Naval Material Command; and Dr. Michael Sovereign, Director of Special Projects, Office of the Assistant Secretary of Defense (Comptroller).

This special section of *Concepts* is devoted to highlights of that panel discussion, including some of the formal presentations and a portion of the transcript from the question-and-answer period that followed. I believe that these highlights will be of general interest to those in the cost analysis community as well as to others in the defense acquisition community who want and need a better understanding of the problems and challenges that face the DOD cost analyst. This increased understanding can only lead to an increased appreciation for the role of the cost analyst in the efficient acquisition of defense systems.

Estimating in the '80s: Panelist Presentation I

SPECIAL SECTION 20

Riner Payne

When I was first asked to participate in this panel, I couldn't help but think back 15 years to the first cost symposium which we had in the Institute for Defense Analysis (IDA) building. At that time the Air Force had just launched a formal program to assemble a data base for cost analysis. We had, about the same time, launched an Air Force-wide program to develop cost estimating relationships. Now, some of you who are about half my age may marvel at the lack of sophistication that this represents; however, to us it represented a giant step forward. I think we've seen many more examples of real progress in the past few years, which brings me to the first challenge that I think we have for the '80s. That challenge is not to become complacent because of the progress you have made. Think to the challenges ahead. We have to make sure that our costing capabilities keep pace with unfolding developments. For example, as we move into the job of costing satellites and space programs, we are dealing with a different kind of technology than we were dealing with when we attempted to cost airplane programs. We are dealing with something where development never ends in the sense that each model differs from its predecessor.

We also have the problem of dealing with the interdependency of systems and subsystems, as illustrated by LANTIRN. This is under development in the Air Force to be common to the A-10 and the F-16. Further, if it works out well, we hope to see it extended into the aircraft of the other services. Now, to the extent that this gives us open-ended possibilities, it represents a challenge to the coster to decide what sort of assumptions he must make in estimating the cost of producing that item.

We're also in an environment of many players from outside DOD. Several of the other speakers have addressed the role of Congress and that of the GAO, as they become increasingly involved in management decisions before the fact.

We have certain unique conditions imposed by the emphasis that has been placed in the last 5 or 6 years on rationalization, standardization, and interoperability. We now have not only our own nation but other nations involved in the development and acquisition of programs. This condition presents a unique challenge to the coster.

Now, obviously, while we are talking about the new things that have to be addressed, we are also confronted with the job of updating our existing data bases and updating our methodologies and techniques. For example, we have on the horizon something called "tailored acquisition." Some of us have worked pretty

Riner Payne is now retired from the position of Deputy for Financial Systems and Analysis, Office of the Assistant Secretary of the Air Force (Financial Management). He previously served in the Cost Analysis Division under the Comptroller of the Air Force. Mr. Payne holds an M.B.A. degree from George Washington University.

hard to figure out exactly what that means, and today it has kind of an "Alice in Wonderland" quality in the sense that you might go around and poll this group and probably get 50 or 75 different definitions of what it means. But I will assure you that should all or many of the components of what we call "tailored acquisition" mature, it will have a rather profound effect on your existing data bases and on estimating the cost of future systems.

I wonder if we are planning to make optimum use of our costing capabilities. Almost every speaker has addressed the requirement to improve the capabilities of our people and to get more costers. I would also like to recognize the fact that technical developments in automatic data processing equipment (ADPE) are just beginning to be exploited in the sense that that they offer us real-time interface between the costers and the managers. I think we should address many of our efforts to research which would permit us to further exploit ADPE in the cost analysis process.

I am a strong supporter of recognition of cost analysis as a professional. There are a number of efforts underway to get us our own job series. I don't know how long that will take, but I think that it will come eventually. The challenge that I would like to throw out in connection with the job series is to safeguard against making cost analysis a cult. If this sounds to you like I am equivocating, that's exactly right, because I think, in essence, what I'm trying to say is that the biggest challenge we had in the '50s, in the '60s, in the '70s, and will have in the '80s, is to maintain perspective in everything we're doing.

I challenge you to better support the managers of the organizations which you serve. You must at the same time avoid the pitfalls of playing politician. Our contribution to management, as I see it, is to give the decision-maker an objective readout of what we think the situation is. Don't compromise yourself by reworking the arithmetic in a way that supports a preconceived solution. It is the manager's job to make the decision.

I suggest that what we need to do first as we move into the '80s is to devote more effort to clarifying our objectives. What exactly are we trying to do in cost analysis? Many of you start from the premise that it is the coster's job to make the estimate large enough that the final answer will not exceed it. But, we have a responsibility to keep the system honest, not just to produce a number that will cover us. I think our responsibility is to decide whether or not it is appropriate to base an estimate on history without further recognition of how new manufacturing processes, new acquisition concepts, new technologies, etc., might tend to modify and, in some cases, reduce the historical costs that you feed into your estimate.

My final point is that we should not become complacent because we are able to acquire a cost analysis job series. That's good, and I hope it comes about quickly. But I urge you to address, in a realistic fashion, the kinds of interfaces we

need to accomplish in the cost analysis community with the budgeteers, with managers, with the GAO, and with the OSD Cost Analysis Improvement Group (CAIG).

In summary, I would like to remind you that our biggest challenge is to keep up the good work. Don't lose the momentum; pick it up. Don't rest on your laurels because we have developed estimating techniques and data bases that have served us well. Maintain perspective in cost research and in the concepts and objectives that you apply to your cost analysis tasks. Improve your coordination with other organizational elements that may have different functional, but related responsibilities.

SPECIAL SECTION 23

Estimating in the '80s: Panelist Presentation II

Joseph T. Kammerer

My discussion of the challenges of the '80s will concentrate on five areas in which we need to improve in cost analysis. This perspective has evolved from experience in my present position, which serves as the focal point for cost analysis in the Naval Material Command. In the day-to-day business with our subordinate commands, the Naval Air Systems Command, the Naval Sea Systems Command, and the Naval Electronic Systems Command, which are the Naval systems commands involved in major weapon systems acquisition, there are several problem areas in cost estimating that continually arise. There are inflation, subcontractor costs, cost estimate tracking, cost management and cost control, and the career development of cost analysts. Let's look more closely at each.

Inflation

We know that inflation accounts for the largest portion of cost growth during weapon system development. The primary reason for this is that we continually underestimate inflation rates used for projecting future-year prices. One who is not familiar with the implications of this procedure might think that it really doesn't matter what inflation rates are used to project prices 5 or 6 years hence because DOD funds are appropriated yearly. The truth is that out-year projections of inflation rates do have a significant impact on the budget year funds requested. The budget for fiscal year 1981 includes what is supposed to be DOD's best estimate to procure ships, aircraft, and missiles appropriated by the Congress for that fiscal year. This means that sufficient funds must be requested to cover expenditures over the next 8 to 10 years in the case of ships, 4 to 6 years for aircraft, and somewhat less for missiles. If inflation exceeds that projected in the funds appropriated, DOD cannot plan on receiving additional funds to cover the inflation. In the case of ships, since most contracts are structured with a contract escalation clause keyed to a Bureau of Labor Statistics (BLS) index, there is a line item in the following year's budget to recoup funds in excess of those budgeted for contract escalation. Such is not the case for aircraft, missiles, and other equipment. Consequently, inflation rate projections are an important part of the process of developing cost estimates. However, making such projections is not part of a DOD cost estimator's job. It may sound silly, but such is the case.

Present rates used in DOD are developed by the Office of the Secretary of Defense under the direction of the Office of Management and Budget (OMB).

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OMB's guidance is usually based on the projected gross national product (GNP) deflator which reflects the administration's view of what will happen to the economy if the administration's planned policies are implemented. This procedure used over the past few years has resulted in low cost estimates in DOD's budget. According to OSD's assessment of the December 1979 selected acquisition reports (SARs) sent to the Congress in March 1980, 48 percent of the total program cost of the 55 SAR systems represents an allowance for inflation. Approximately 72 percent of this is unanticipated inflation that was not recognized when the development estimate was originally prepared. Is it possible to do a better job of projecting inflation rates for defense expenditures, and should we?

Many cost analysts shy away from projecting the impact of the economy on future defense expenditures. The excuse is often given that such projections are too subjective, too uncertain, and would be viewed as guesswork. The current procedure also allows us to conveniently place the blame for cost growth on inflation, an economic force beyond our control. However, there are alternative views which appear much more sensible for DOD and for the profession of cost estimating and cost analysis.

The inflationary effects of defense programs are too important to ignore or to pass off *the responsibility for projecting and monitoring these effects* to a second or third party. In addition, the actual price increases which are the result solely of market and economic conditions will vary from company to company and even product to product. Part of the job of the cost estimating and cost analysis community should be to closely monitor these trends on a weapon-system basis. Only then will we have a more realistic picture of what *has* happened to prices, what *is* happening and what *is likely* to happen in the future.

To assist in his monitoring and projecting of inflation on a weapon-system basis, the cost analyst should make use of the macro-economic forecasting services available from several reputable economic forecasting firms. These experts, who are involved in projecting the overall economic conditions likely to prevail in the future, have developed very sophisticated models that simulate economic interactions resulting from economic policies, legislation, and the worldwide economic state-of-affairs. It is true that results of these macro-economic models are highly dependent on key assumptions concerning the level of federal spending, and whether or not legislation such as the Kemp-Roth tax laws are passed. However, as in all analysis, a complete communication of the underlying assumptions should be required. The impact of any assumptions can be easily tested in the available macro-economic models.

During the summer of 1980, the Defense Science Board was especially interested in communicating to DOD the impact of inflationary effects in the aerospace industry during 1980. The Board not only made inquiries through their industrial representatives, but the Chairman also requested the opinion of the

Chief of Naval Material. In developing our response to the Defense Science Board, we enlisted the macro-economic services of one of the major economic forecasting firms. Using the results of the macro-economic models and developing some simple models that would reflect what was happening in ships, missiles, aircraft, and research and development costs, we were able to compare what was actually happening in 1980 to what we had projected using the latest OSD/OMB indices. We extended the analysis to make use of the forecasting firm's long-term, 10-year forecast to make comparison with the OSD/OMB indices for future years. We then calculated the dollar impacts of these out-year projections on our near term 1980 budget supplemental and 1981 budget amendment requirements.

The results of the exercise are shown in Figures 1 through 3. Figure 1 shows the firm's projections for aircraft (APN), missiles (WPN), and other equipment (OPN) compared to the OSD/OMB procurement index. Figure 2 shows the ship construction index (SCN) compared to the OSD index for shipbuilding. Figure 3 shows the firm's projection for research and development (RDT&E) compared to the OSD/OMB index for research and development. Figures 4-6 show the actual inflation rates shown in Figures 1-3.

We found that the firm's projections closely approximated the OSD projections for 1980 and 1981, but beyond 1981, the firm's projections were significantly above the OSD/OMB rates. This pattern of low inflation rates in the out-years has remained consistent over the last decade. The low rates in the out-years create a very real near-term problem because they cause shortfalls in the near-year appropriations resulting from the application of outlay rates. The funding impact for the Navy's FY-80 Supplemental request and the FY-81 Budget Amendment are shown in Figures 7 and 8. Using the forecasting firm's rates instead of the OSD/OMB rates yields a difference in the five appropriation accounts of $985.5 million for the FY-80 Supplemental and $1,190.5 million for the FY-81 Budget Amendment. This is a significant amount of money which, if not recouped, will leave no alternative but to reduce the quantities of weapon systems authorized by the Congress for procurement.

We can, and we should, do a better job of projecting inflation in weapon system cost estimates. We should monitor inflationary trends on a weapon system component level, e.g. aircraft engines, airframe, avionics. The services should also encourage OSD to propose new ways of projecting inflation rates to OMB. The present techniques of deriving the rates from the GNP deflator is obviously not giving us good projections. Regardless of whether or not OSD succeeds in making such a proposal to OMB, the services should direct their cost estimators and defense contractors to track actual inflationary impact by weapon system component. This is so important because double-digit inflation will most

FIGURE 1
Cost Escalation Indices – Procurement EX Ships U. S. Navy

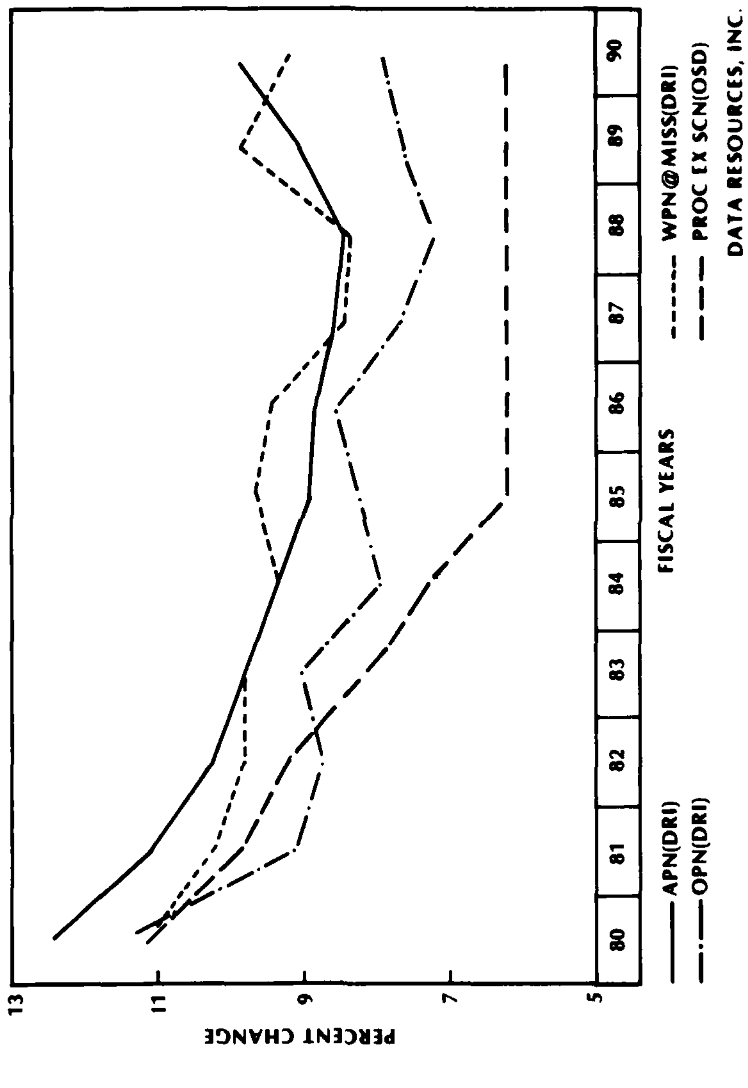
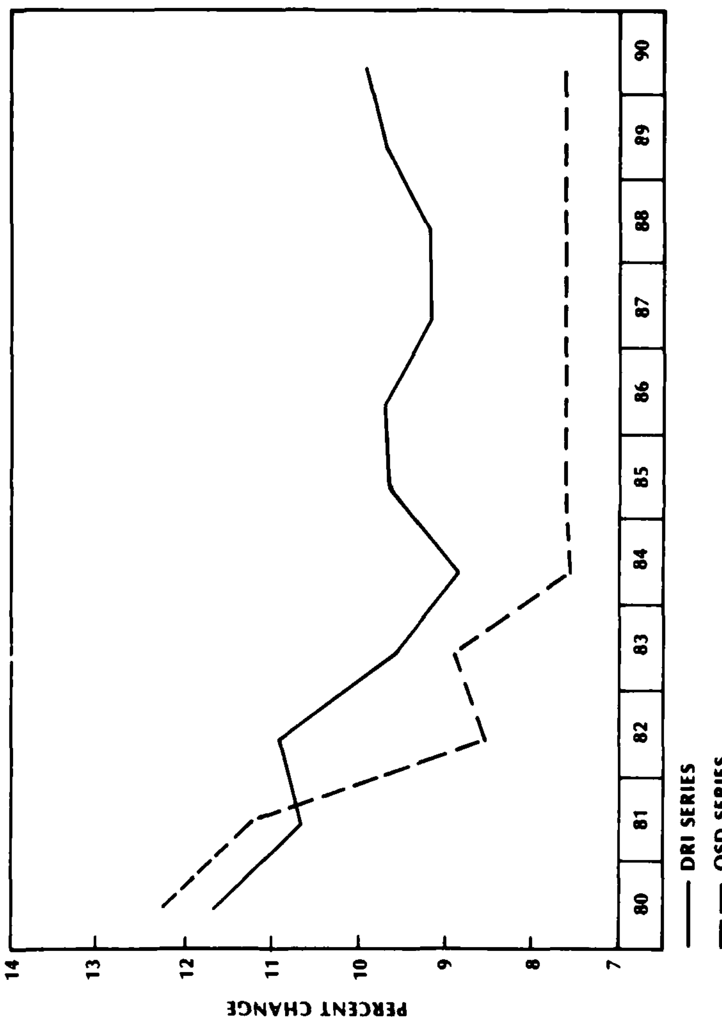


FIGURE 2
Cost Escalation Indices – Ship Construction U.S. Navy



DATA RESOURCES, INC.

FIGURE 3
Cost Escalation Indices - RDT&E U.S. Navy

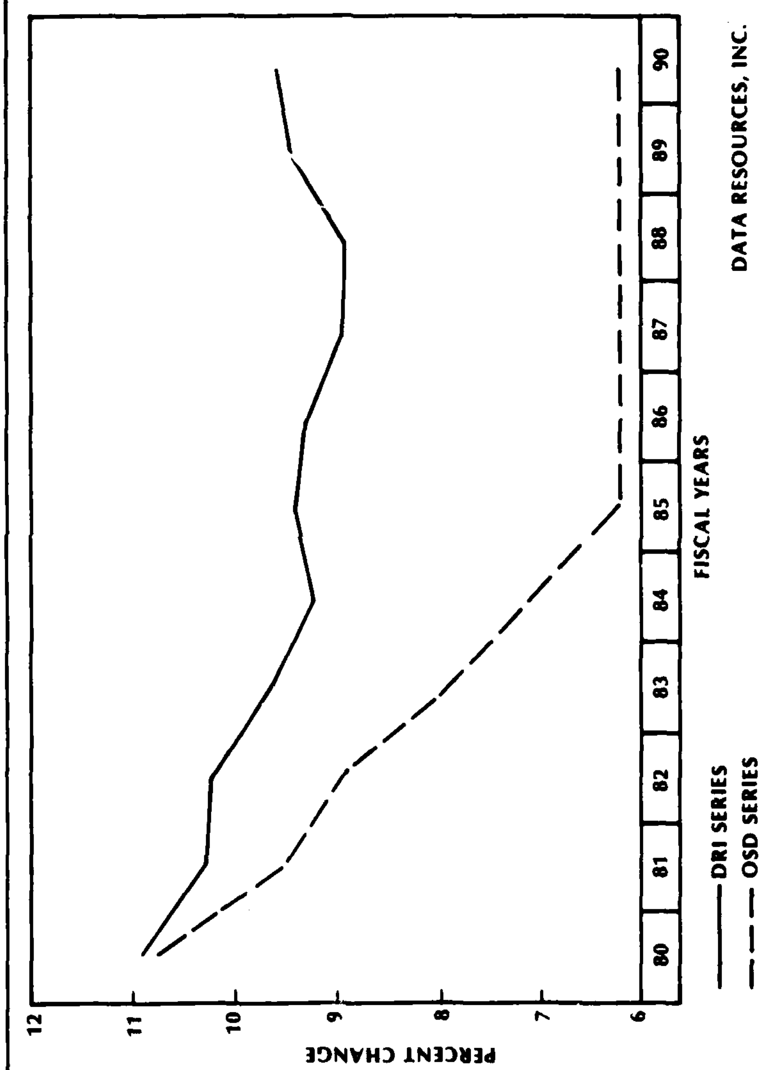


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FIGURE 4
APN/WPN/OPN Inflation Rates %

	80	81	82	83	84	85
FY - 80 BUDGET	6.2	5.6	5.4	5.4	5.4	5.4
FY - 81 BUDGET	8.6	9.0	8.5	7.8	7.0	6.1
FY - 80 SUPP. & FY - 81 AMEND.	9.3	9.7	8.9	8.1	7.2	6.2
OSD - JUNE 25	11.1	9.9	9.3	8.2	7.3	6.2
DRI - JULY 25 -APN	12.5	11.1	10.3	9.9	9.4	9.0
-WPN	11.1	10.3	9.9	9.9	9.4	9.7
-OPN	11.4	9.2	8.8	9.1	8.0	8.3

FIGURE 5
SCN - Inflation Rates %

	80	81	82	83	84	85
FY - 80 SUPPLEMENTAL	8.0	8.0	6.5	6.5	6.5	6.5
FY - 81 AMENDED BUDGET	8.2	8.2	7.8	8.5	7.2	7.5
FY - 80 SUPPLEMENTAL & FY - 81 AMENDED BUDGET	10.5	10.9	8.2	8.8	7.4	7.6
OSD - JUNE 25	12.3	11.3	8.5	8.9	7.5	7.6
DRI - JULY 25	11.7	10.7	11.0	9.6	8.8	9.7
NAVSEA	10.8	8.9	8.8	7.9	8.2	7.1

FIGURE 6
RDT&E Inflation Rates %

	80	81	82	83	84	85
FY - 80 BUDGET	6.3	5.8	5.5	5.5	5.5	5.5
FY - 81 BUDGET	8.2	9.8	8.2	7.5	6.8	6.1
FY - 80 SUPP. & FY - 81 AMEND.	9.0	9.4	8.6	7.8	7.0	6.2
OSD - JUNE 25	10.8	9.6	9.0	7.9	7.1	6.2
DRI - JULY 25	10.5	10.2	10.1	9.7	9.4	9.4

FIGURE 7
Impact on Navy's FY-80 Supplemental Request

	(MILLIONS OF THEN-YR DOLLARS)				
	APN (AIRCRAFT)	SCN (SHIP-BUILDING)	WPN (MISSILES)	OPN (OTHER EQUIP)	R&D (RESEARCH & DEVELOPMENT)
OSD/OMB RATES	530.9	828.6	256.8	306.6	272.3
DRI RATES	794.5	1315.0	334.8	363.8	372.6
DIFFERENCE	263.6	486.4	78.0	57.2	100.3

FIGURE 8
Impact on Navy's FY-81 Budget Amendment Request

	(MILLIONS OF THEN-YR DOLLARS)				
	APN	SCN	WPN	OPN	R&D
	(AIRCRAFT)	(SHIP-BUILDING)	(MISSILES)	(OTHER EQUIP)	(RESEARCH & DEVELOPMENT)
OSD/OMB RATES	89.6	330.0	43.3	56.8	64.8
DRI RATES	441.5	860.5	164.9	134.7	173.4
DIFFERENCE	351.9	530.5	121.6	77.9	108.6

likely persist throughout the 1980s. If there is to be "real growth" in defense expenditures as planned, DOD cost estimators must be able to tell top management the right amount of money to budget for weapon system procurements to permit the real growth to occur. Former Secretary of Defense James Schlesinger, in a *Wall Street Journal* editorial of October 24, 1980, said that it would take $10 billion more to execute the President's program in the FY-81 budget submitted to Congress in January 1980. Although inflation between January and October was probably more than anticipated by most economists, the budget reflected overly optimistic projections. A better job can be done and DOD cost estimators should lead the crusade.

Subcontractor Costs

Certainly one of the challenges of the '80s is for DOD cost estimators to pay more attention to subcontractor costs. The "make vs. buy" decisions being made by our prime contractors are having a larger impact on cost growth than ever before. The complexity of today's weapon systems makes it desirable for a prime contractor to seek the services of the increasing number of specialty shops. A technique that is often employed by the prime contractor in attempting to get the best arrangement with subcontractors is to give a firm order with options for future buys. The prime contractor often attempts to fix a price at the time the initial orders are placed. As the procurement proceeds and the prime contractor does not establish a second source, the subcontractor often takes the position of a sole-source supplier. When the options are completed from the initial buy, he raises his prices significantly. Such was the case in both the F-15 and F-18 pro-

curements and, with the inflationary trends projected for the 1980s, we can expect such price increases from subcontractors and vendors to become commonplace. Often when the subcontractor has agreed to a price, he may find himself making no profit or accepting a loss in the last year of the option. He will then attempt to correct his position with price increases. The result seen by the prime contractor and the DOD program manager is a significant increase which comes as a surprise to DOD managers. Cost estimators must make DOD managers aware of this situation and budgetary estimates should be adjusted to reflect subcontractor relationships with prime contractors. A closer monitoring of subcontractor costs must remain a top priority for DOD cost estimators. In addition, our cost collection systems should be adjusted so that monitoring of subcontractor costs is enhanced.

Cost Estimate Tracking

Whenever a Navy weapon system program has significant cost-growth problems, the questions from top management are, "What happened? Where did we go wrong in estimating the costs?" The answers are often not readily available and the reason is the lack of good cost estimating documentation. In order to track cost estimates, good documentation is essential. Even when there is fairly good documentation, the question can often not be answered satisfactorily because cost estimators do not track cost performance very well. We need cost analysts who can understand the implications of not meeting performance specifications and who understand the cost uncertainties associated with technical performance characteristics. We need cost analysts who will follow the details of engineering changes made throughout development and early production so that cost estimates can be tracked better. The tracking of cost estimates can be a full-time job requiring intelligent analysis in terms of what is significant and what is not and the impact on future buys. To do this requires a good understanding of how the contractor incurs cost and how he tracks cost. In tracking costs, we need to be able to isolate production rate effects to be able to better articulate the impact of ineffecient utilization of defense facilities and resources. Certainly then, a challenge for the '80s is to be able to track costs better.

Cost Management and Cost Control

Cost analysis should be used in weapon system procurement from the planning stage until the weapon system procurement is complete. It should be used as a tool to enhance cost management and cost control. Navy experience shows that program managers tend to pay more attention to meeting technical performance specifications and planned delivery dates in weapon system acquisition than they do to cost management and cost control. Regardless of the problems we have in

obtaining funds for weapon system procurement, we tend not to be serious in implementing good cost-management and cost-control techniques. DOD cost estimators can and should pay a vital role in helping program and financial managers to bring about better cost management and cost control. In developing the initial cost estimates and tracking costs through program development, the cost analyst can provide insight to the program manager from this valuable experience. He can tell the program manager where the soft spots and the significant "cost drivers" in the cost estimate are in order to direct his attention for cost management to the right areas. The cost analyst can keep contractor surprises to a minimum by close tracking and can suggest management reviews when his cost analysis indicates the need. There is no question that cost estimating and analysis is applied to a much greater degree at the front end of program acquisition than in the later stages once production has started. But, it is in this stage of program execution that cost control techniques should be applied rigorously.

The cost analyst can assist the contract personnel in this stage in following overhead costs. At one time, DOD was very interested in tracking defense contractor overhead charges and initiated the PIECOST system to assist in this effort. Although PIECOST fell out of favor because of the large resources needed to implement the system, we have seen overhead charges increasing steadily since its demise. Perhaps we need to take another look at PIECOST or a derivative of PIECOST to help us better track and control overhead charges. The challenge for the '80s is to exercise better cost management to bring about better cost control in our weapon system procurements.

Career Development

There is no doubt that the profession of cost analysis and cost estimating is suffering because we cannot attract and keep the caliber of people needed to do the job right. Our good people are seeking employment outside of government because we have failed to provide them with a good career development program. We need to propose a "GS series" for cost estimators and analysts to the Office of Personnel Management. The Army has led the way in pioneering such an effort but they have lacked the needed support of the other services and OSD in bringing about its implementation. If costs are of primary concern in DOD, then we must provide the department with a means for obtaining the best people with the right educational background to do the job. We need to concentrate on the "multi-discipline" approach to cost analysis. The profession needs engineers, statisticians, economists, operations research analysts, program analysts, financial management analysts, system analysts, mathematicians, computer experts, and experts from related fields. Without the influence of all these areas of expertise, the profession cannot function efficiently. The challenge for the '80s is to

develop a meaningful career development program for cost estimators and analysts.

The five areas discussed above represent specific areas in which improvement in cost analysis is needed. They represent my view of the challenge for the '80s. But, we should not stop at these challenges. By concentrating on objectives of the Under Secretary of Defense for Research and Engineering, it is easy to see additional challenges for the cost analysis community in the '80s.

Two objectives of defense investment for the '80s, as stated by the Under Secretary of Defense, are to modernize U.S. deployed defense systems, and maintain leadership in the technologies critical to defense. Because of the cost of modern weapon system acquisition, we will see much more emphasis being placed on modernization of existing weapon systems as opposed to acquisition of new ones. As cost analysts, we must be ready to meet this challenge in estimating modernization costs. Within the Navy, estimating modernization costs is a weakness, especially in our Washington-based system commands. Perhaps we should develop that expertise at a field activity—perhaps a Naval shipyard or aircraft rework facility. We also have a weakness in estimating the costs of weapon systems which utilize new technologies, and in estimating the cost of developing new technology. This is definitely an area in which cost analysts will find a challenge in the '80s.

Figure 8 shows some management initiatives and objectives continuing in the '80s and we need to be prepared as cost analysts to assist. Do we really know the cost impact of increased competition in procurement? In most cases competition usually costs more at the outset to reap downstream benefits. But, as a community, we lack sufficient data to adequately assess the effects of competition. This is certainly an area in which cost research could help us.

Another area requiring emphasis by cost analysts during the '80s is manufacturing technology. Again, DOD cost analysts are not experts in this area and we need to think about how we are going to get the proper assistance in this area. Extending the useful life of existing systems, which applies directly to the Navy's carrier service life extension program (SLEP), creates a challenge for the cost analyst. The life of aircraft carriers is being extended from 30 to 45 years in this program and the cost for the first one is in the order of $500 million. Navy cost analysts have prepared studies to compare the costs of doing the job in public and private shipyards in accordance with OMB Circular A-76. There will be more such studies in DOD and the cost analysis community will find it a challenge for the '80s.

With more attention being given to cooperation with U.S. allies to develop and produce weapon systems, we must be prepared to pay more attention to coproducton costs and offset agreements and their impact on our weapon system prices. We are faced with the challenge of efforts to shorten the acquisition proc-

ess. This usually will result in concurrency in development; we as cost analysts must be prepared to properly assess what concurrency means in terms of cost. If technical problems occur during concurrent development that result in increased cost in production, the cost of making the technical fix after production has started must be assessed. This complicates the job for the cost analyst and will make him concentrate more on cost risk and on reflecting that risk in terms of a cost range.

The '80s present some interesting challenges for cost analysts, both from an introspective, self-improvement aspect, and from new initiatives and objectives proposed for weapon system acquisition and modernization. Certainly the challenges are there; finding the right people with the right background to do the quality work that we all expect may be the ultimate challenge for the '80s.

Estimating in the '80s: Panelist Presentation III

SPECIAL SECTION

36

Dr. Michael Sovereign

Last year at this meeting, I gave a paper entitled "The Decade of The '70s, Improvements in Cost Estimating." In it I cited the development of the Cost Analysis Improvement Group (CAIG), the selected acquisition reports (SARs), the cost performance reports, the VAMOSC system, the Bureau of Economic Analysis inflation measurements of weapon systems and, in general, a higher standard of professionalism in the cost community in the broad sense. I think there really were improvements in the '70s. It was the spreading of professional knowledge and the acceptance of the computer as a tool which were the greatest forces, in my opinion, behind the improvement of the 1970s.

Well, what challenges are to be met in the '80s and how will we meet them? Certainly they have not changed in their general scope since the '70s. First, we *must become more professional*, i.e., more thorough, more realistic, more able to support the decision-makers, and more willing to admit that this is a difficult business and that we don't have all the answers. I think it is amazing that, independently, all of the five of us raised the professionalism issue in our talks, and I think this is the decade for us to really make some radical, formal, and substantial improvements in the professionalism of the group. Secondly, we must use the computer to link the detailed knowledge of those out in the field with the review and planning process in headquarters. As Mr. Payne said, there must be a closer communication between the field and headquarters. The computer and telecommunications revolution is really the answer to that, and I think we will take advantage of it in the next decade. Sometimes we here in Washington are guilty of thinking of both the government's and the contractor's accountants and others in the field as enemies instead of potential allies and possible monitors of the resource activities that drive our estimates. We have got to communicate better with the field people. That's enough philosophy.

I would like to discuss four areas for the '80s which I divide into problems of a conceptual nature and problems of an organizational nature. Conceptual problems require new or more definitive theoretical guidance. Organizational problems are largely ones of implementation, but may require substantial organizational change, which is always difficult. In the conceptual area, I would like first to point my finger at the fundamental area of cost estimating relationships (CERs), which have been a major tool in the costing revolution.

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Some people refer to this as the small-sample problem. This problem is definitely getting worse as we are able to afford a smaller and smaller number of new systems on a periodic basis. I believe this is an even more fundamental problem than the legitimate small-sample problem in a statistical sense. In producing CERs and then treating them as statistical forecasts, we are violating the fundamental principle of statistics, which is that our data must be samples from a definable, single population. As Mr. Payne just said, the reason we design new systems is that they are different, otherwise we would buy more of the old ones. We must be aware of this problem and not mislead the decision-makers on the accuracy of our forecasts. Well, what can be done about this problem? An extreme, or puristic, view would be that we can do nothing about it, and we should just ignore any statistical properties of the cost estimating relationship. However, I assert that this is more defeatist than we need be. We can start by interpreting our results as a lower limit on possible errors. We should never say how good it's going to be, only that it may be at least this bad an estimate. We can't guarantee that we will be as good as we say our confidence intervals are, because we disobey the basic assumptions of statistical sampling. In this respect, we have been particularly careless, I think, with the statistical difficulties of combining estimates of unit costs with the learning curve, which we then apply together to get total program cost. The uncertainty within the total program cost is much larger than we often convince the decision-makers there is, as borne out by retrospective examination of the cost estimates.

Another Approach

Another approach is simply to be more careful in selecting the data base we use in deriving a CER for a particular new system. We can try to have systems that are fairly similar. They may not be exactly the same as the system we are trying to estimate the cost of, but let's at least pick a data base of similar systems for CERs. The computer and the spread of statistical capability in the profession has made it easy to derive CERs for individual new programs rather than looking for one CER for airframes that we will use regardless of what kind of airframe it is, say a CX, or a fighter, or so forth. I call this general problem of data selection for a particular system the aggregation problem in forming a CER. It really has two dimensions. One is: What kinds of systems do I include in the data base for my CER—bomber, cargo, or fighter? The other question or dimension is at what level of system do I attach this problem? What do I derive the CER for—for the whole aircraft, for the airframe, for the fuselage, or for wing structures? In other words, at what level of system or subsystems do I attack the problem? Attacking the problem by subsystem is often profitable because the various subsystems have differential maturity.

The cost of an engine from an existing aircraft is well known. There isn't much uncertainty in the mature subsystem. We can often get a measure of uncertainty by breaking the system down. You are all familiar with those general questions. Typically, we address those questions of what kinds of systems to include in the data base and whether to attach the problem at the system or subsystem level intuitively. We usually just use judgment in determining the answers to those questions.

I believe that's a reasonable approach until our friends from the audit agencies ask us to document why we selected certain systems to put in the data base. We probably are going to have to do better than just rely on judgment in determining these answers. There are some statistical techniques becoming available which we should be working on to address questions of what can be treated as one population from which to draw a CER. There is the Chow test for deciding if two samples can be treated as coming from the same populations. There is work going on by Professor Ted Walhenias of Clemson. He uses what is known as the Mahalanobis distance for measuring quantitatively how different various weapon systems are from each other. This can then be used in determining what points to put in the data base. In general, data analysis techniques that require fewer distributional assumptions may be useful in segregating some populations. However, whenever we use data-analysis-type techniques such as stepwise regression, we have to be very careful about the statistical properties of the resulting CERs. In summary, I believe there will be a very useful interaction between theoreticians and practitioners in the area of development of better methods for selecting the data base for CERs in the 1980s.

Personnel Costing

The second area in which I see some conceptual difficulties and challenges is that of personnel costing. By this I mean, in the simplist sense, what's the cost per man-year? That seems to be a fairly simple thing, but it gives us some difficulties. I think we still see bad decisions by decision-makers who don't appreciate the full cost of manpower, or people, if you prefer. Some of these decision-makers are mislead by conventions we adopt, such as the CAIG guidance that says the operating and support cost estimates we make should use the costs per man obtained by simply taking the total wage costs in the service and dividing by the number of enlisted men in the service. There is no allowance for skill or rank in those kinds of numbers. Putting together operating and support costs based on those kinds of costs per man is misleading. The disappearance of the draft has removed the last excuse for us to disregard the cost of our human capital. I believe that unless we adopt the human capital costing procedures for this area, we will find ourselves with truly catastrophic situations in the near future as eligible populations decline and skill levels must increase. Yesterday it was pointed

out by one of the panelists that the number of additional military manpower assumed by one of the other panelists was larger than the population coming into the eligible area for our manpower in that 5-year period. So we have a real problem which must be met, I believe, by better accumulation of the full costs of procuring, training, maintaining, and supporting our personnel, including retirement costs. If we use that total cost, we will be able to reject new, manpower-intensive systems in favor of those which require fewer and less-skilled manpower. We will be able to show that personnel retention measures are cost effective and avoid many of the problems of rapid turnover that we have had in the military.

We must give up our convenient but conceptually inadequate idea that cost is reflected in what we pay people. Opportunity cost is the only appropriate measure, and productivity should be the indicator, not just pay. The training that we give our personnel creates opportunities for employment, or alternative employment, which we should recognize in our costing or we are going to see our best people continue to leave the military services. A new manpower costing system must first of all reflect the costs of training, if not the value. It must reflect relative talent levels of people. The real cost of the Navy's nuclear program is, I believe, substantially understated by the fact we send the best people into that program. Many other areas simply can't get that same quality of manpower, which they also need. Finally, a new system must treat manpower costs as a stream including the recruitment and the retirement costs. There are difficulties conceptually with retirement costs, including: What is the real growth of pay over the next decade when these people will retire? What is the opportunity cost of capital which should be applied against any offsetting deductions of their retirement pay? This new methodology for assessing personnel costs should enable decision-makers to keep track of the stock of military human capital and what is happening to it, and make better decisions on both its use and level.

Implementation Challenge

The second area I would like to talk about is the implementation challenge we will have in the 1980s. I have picked out two here that are relevant to the kinds of things I'll be doing. First is a coordination of life-cycle weapon system costs with long-term budgeting. We must bring together the life-cycle costing people and the budget-analysis people. Conceptually, it should be possible to build budgets by knowing force levels and acquisition plans for new systems, along with the life-cycle costs of both the new and existing systems. Indeed, the Army, under Wayne Allen's leadership, is attempting to do just this. In the first issue of the new *Resource Management Journal* the Army is putting out a very nice account of what Wayne is trying to do. I believe more connections can be drawn between existing operating and support cost reporting systems and the budget and plan-

ning processes. There is a cost-of-ownership project going on in OP-96 in the Navy, under Irv Blickstein; there is Charlie Groover's Logistics Resource Annex coming out of OSD(MRA&L); there are the VAMOSC systems. We need to put all of those together to allow us to be able to bridge this long-standing separation of the acquisition and the budget-analysis cost communities.

Finally, I would like to speak a little bit to the inflation problem, which Joe Kammerer raised, particularly his treatment of the rates imposed on us as OSD inflation rates. Coming from the Comptroller's Office where we put these out, let me tell you that those are not the rates we would like to see. Those are the rates imposed on us by the Office of Management and Budget. If you heard Mr. Sitrin yesterday you know that indeed they are finally at the point of looking at better systems for dealing with estimating inflation.

Same Inflation Rate?

One of those is the use of more detailed rather than aggregate measures. One part of OMB's problem is that they want to give us the same inflation rate as any other agency, but we spend about 98 percent of the Federal Government's money on fuel. Since fuel has been inflating very rapidly, it is quite obvious they are going to have to treat us differently in that area. OSD did step out of bounds, i.e., outside the guidance given by OMB this year, and allowed the services more for fuel inflation. By doing that I think we finally got OMB's attention to the need to create inflation measures which break down to commodity level. To do that better, we need better ideas as to what tailored price indices would be for aircraft and ships. Now, you say we already have those, but the one we use for ships, the last I knew, was still based on a 1950s cargo ship. The one which is used in some areas for aircraft, for example, by the Congressional Budget Office is also based on a commercial aircraft of considerable age and doesn't include avionics. We really need better ideas from all of you as to how to tailor indices for specific weapon systems. We need to have better historical collection of inflation as well as projections for the budget years. The Bureau of Economic Analysis (BEA) has finally put together an effort to collect historical data, but there are some difficulties with that effort. It needs to be accepted over in BEA for use as the federal defense deflator, which it currently is not. We need to coordinate throughout the system so that we have identical approaches or at least close-to-identical approaches to measurement and planning for inflation rather than one measure being used by CBO, another by OMB, another by OSD, another by NAVAIR, NAVSEA, Air Force, and so forth. We need to get together on those, and I intend to see that that happens. And, finally, we need to set up a system which reconciles our estimates of inflation with the actuals. Those are the challenges I see. ‖

SPECIAL SECTION

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Estimating in the '80s: Question and Answer Session

As part of the "Estimating in the '80s" general session meeting at the Fifteenth Annual Cost Analysis Symposium, questions were taken from the floor and addressed by one or more of the key people in cost analysis assembled to participate in the panel discussion. A portion of the transcript from that session is presented below. The panelist or panelists responding to each question are identified by name. The panel was moderated by Leroy T. Baseman, Chairman of the Air Force Cost Analysis Improvement Group. Participants on the panel were Dr. John Morgan, Director, Cost and Economic Analysis Directorate, Office of the Assistant Secretary of Defense (Program Analysis and Evaluation); Mr. Wayne Allen, Director of Cost Analysis, Office of the Comptroller of the Army; Mr. Riner Payne, then Deputy for Financial Systems and Analysis, Headquarters U.S. Air Force; Mr. Joseph T. Kammerer, Director, Cost Analysis Division, Headquarters Naval Material Command; and Dr. Michael Sovereign, Director of Special Projects, Office of the Assistant Secretary of Defense (Comptroller).

Question: I'm pleased that we are talking about challenges of the '80s. I'm saddened that we missed what I consider the most significant, that being a time to freeze requirements. We all know that what drives our cost estimates is not better CERs, or better data bases, or better mathematics, or better communications. In my view it is this constant, incessant, undocumented, creeping problem of changes in requirements. So I would throw a challenge to each of you individually to influence and to do what you can to at least put a pause to this constant change in requirements so that those of us who have to make cost estimates can do that better job that you ask us to do.

Response (Allen): We are talking about a systemic problem. It is a problem of how do we obtain increased stability in the acquisition process, or, said another way, how do we minimize disruption? That, in the Army's case, gets back to something as fundamental as our internal requirements-setting process, how many players we have in that process, and how many times those players are second-guessed as requirements issues pass up and down the hierarchy. The number of voices that must be accommodated contributes to the instability in the requirements over time. All of which says, I don't have a good answer to your question. I have noted that, within the Army, we are talking about requirements stability and this is at the three- and four-star level. However, institutionally and systematically, we tend to shy away from the word "freeze" as we want "flexibility." It has to do obviously with such things as the annual funding or annual budgeting process and how that process causes instabilities, and a lot of that is

beyond our control. But we can't carry that thought too far or it can become a cop-out for not trying to bring stability. There are some mechanisms that we are working with in the Department of the Army to try to bring about increased stability. One such mechanism is a better statement of materiel system requirements from the outset to reduce downstream turbulence.

Response (Kammerer): In responding to your comment, Wayne, it seems to me that we, as cost estimators, may be part of the problem, and I think we should take part of the blame. After all, if our cost estimates were not continually changing, the decision-makers would not have to change their quantity requirements. When one weapon system constitutes, say 25 percent of your procurement dollars, and suddenly increases in cost estimates raise the ratio to 50 percent of available procurement dollars, something must be cut in order to live within the constraints. Cuts in quantities raise unit production prices and it's this sort of dog-chasing-its-tail syndrome that takes place.

Response (Sovereign): We can't simply freeze requirements; we all know that. What we need to do is better understand and better plan for those requirements. The design-to-cost type of question, the affordability question, those things have to be integrated in the bigger picture of cost estimating. And, if you can't hang on to all of those, you don't have a program that's going to be stable, and I think it is program stability rather than requirement stability that we need.

Response (Morgan): I'm not sure I understand exactly what you mean by "changing requirements." Are you talking about modification programs, the conventional ship problem? We can't get a ship built for a reasonable cost because there are frequent revisions that change the configuration of that ship, for example, to put on new weapon systems, or new electronic capabilities. Or are you talking in a larger sense about the characteristics of total weapon systems as related to the threat that faces us and as required in the initial acquisition specifications? If you are talking about the latter, it seems to me that you are confronting a hopeless task if you think we are going to forego the opportunity to develop a better new weapon system capability in regard to the threat. Now, if you are talking about the former, that is a question to some extent of discipline and management in freezing a configuration and sticking to it. Which is it that you mean?

Questioner: The characteristics.

John Morgan: In other words, alternative one, the constant change in the ship before you can get the thing built. Well, I contend that you are speaking about a problem that is beyond the capability of this panel to address. Our only hope as cost analysts is to point out the cost implications to the managers, but they still will make the final decisions

Response (Payne): Yes, I think we ought to take into account Dr. Perry's pitch for affordability analysis. While, from a cost analyst's point of view, life would be much simpler if we cut out the turbulence, we have to recognize that we need

to enhance characteristics in a lot of cases to keep up with the threat. If the system works properly, the cost analyst's job is to provide good alternative costs so that the DSARC can do its proper job. Obviously, we have configuration control boards and a lot of things like that which presumably tend to restrict modifications in major systems to those things that are generally agreed to as essential. I don't think there is any realistic expectation of freezing changes merely to accommodate the costers, nor do I happen to think it desirable.

Comment from the floor: I think what the gentleman hit on was the real challenge of the '80s. We are not going to settle or stabilize the financial management system or the requirements for weapon systems or any of these other things. What our real challenge is, is to adapt our methodologies and our techniques to accommodate these so that we can do our job even better.

Question: With regard to inflation, which seems to be the most common denominator judged by all the panel members, for 10 years we have been using OSD/OMB inflation factors. And we keep saying that the factors are never what they should be, and are continually critical about what is published. I just wonder if we shouldn't perhaps be more concerned with exacting nominal factors and living with those factors for inflation, making periodic changes as opposed to issuing OSD/OMB factors three times a year, which causes tremendous aggravation and gyrations of the system. It is not so much the mechanics and methodology of how to determine whether it should be the GNP deflator or some nominal factor of 5 to 10 percent, but establishing a procedure. I think OSD owes us leadership which provides for a more stable, uniform application and treatment of how the mechanism will exist. Now, with regard to individual systems and projects, because no nominal value would ever be right, as no published GNP deflator would ever be right, what is the mechanism that would, for example, provide extra funds when the XM-1 tank actual inflation is 12.2 percent and the GNP deflator value published by OSD is 9.1 percent? We need to get a uniform approach. We simply need leadership in the policy area.

Response (Sovereign): There are several things in what you said. The last item I listed was a system for reconciling our estimates and our actuals, and that's probably more important than a precise estimate of what inflation is going to be. I totally agree with you and I think we are going to move to do something there. Now, your other point was the three-times-a-year adjustments. There again we are driven by the President trying to put together a budget in the January time frame to send to Congress. If we have a shorter planning process, maybe we could reduce that from three to two times, but I don't think we are going to be able to independently step out and send over a budget which is based on a nominal rate whereas everybody else is using what OMB tells them. Does that partially answer your question?

Question: It answers it, but it does not satisfy me.

Response (Baseman): I would like to make a comment on the general subject

of inflation. We have not addressed the thing that goes with the DOD inflation rates and that is the combination of the inflation rates and the expenditure patterns. In a lot of cases we are not hurting as much as we say we are hurting.

Response (Kammerer): In my presentation, I mentioned the outlay rate problem. It seems that the OSD inflation rates are always low in the out-years. And yet, it is these inflation rates that are used in calculating near-term appropriation dollar requirements when we take account of the expenditure profile. These rates, then, are very important in calculating the dollars necessary to execute a program: We must do a better job of forecasting the out-year escalation rates with more realism. Remember, we are not recapturing these funds that we lose. OSD revises the rates three times a year and there is always the proclivity to forecast low rates in the out-years. I would like to see the services coming forward to OSD, as the Navy does with their shipbuilding indices, saying this is what our research has shown, this is what we think the economy will do to our programs, and we would like to have OSD review and approve the indices we have developed for our programs. I believe this should be the procedure. If OMB is open to this procedure, and we can convince them, then we should institutionalize the process. I think sitting back and accepting the OMB/OSD inflation indices is not the way to proceed. We must step forward and do a better job ourselves instead of just complaining that the rates are too low.

Response (Baseman): Joe, I have to interject a point: Is it really possible to convince anyone of what actual inflation has done to us, unless we create a system for measuring the impact of inflation we experienced? I don't know how it is in the Navy and the Army, but quite frankly I don't think we in the Air Force have a thorough enough system for determining what the impact of inflation has actually been. By the time you work down to jobbers and sub-jobbers and fifth-tier subcontractors, we can only generalize as to what we have actually experienced. Until you can do that, can you really sell something different from what we are given?

Response (Kammerer): Although I think it's a difficult problem to measure the inflation we have experienced in our systems, I do agree that we need to do it—it should be one of our top priorities. I think this is what Mike Sovereign has been advocating.

Question: Does the government ever try to determine the effect of our publishing our planning information? I can think of two situations: One, the Navy has the fleet modernization program wherein we list the planning figures for all the ship alterations; therefore, contractors know what the customer is willing to pay for the job. In the case of inflation, if we get higher rates and publicize this, won't industry learn of them, and won't it have the effect of increasing inflation?

Response (Morgan): I'd like to say something, if I may, on this question of inflation. As you probably know, there are occasions in our analytical activities in

OSD when we take into consideration what we call progam-unique inflation guidance in putting together the POM and budgets. In providing this guidance, I'm not saying the rates are always right. Don't misunderstand me; I think we really should know what the different rates are going to be by different resource areas. But I don't think in putting together a POM or budget that you can always get down to sufficient detail to have variable rates for all kinds of resource areas of weapon systems. Furthermore, I'm not confident that the decision-making is going to be influenced dramatically by having absolute accuracy and ability to forecast inflation rates. I think decisions are made on different allocation bases than that. So number one, program-unique inflation is recognized in analyses that we do as we are moving into the production phase on weapon systems and we have the services provide those to us. Secondly, I don't think that resolution of the inflation rate projection 2 years before you are going to start the full-scale engineering development of a weapon system is going to be a major influence on the decision.

Response (Payne): I'd like to add to that. I think, and I say this at the risk of being drummed out of the fraternity, if you look at the iterative nature of the budgeting process, an understatement of inflation at a given point in time presumably is correctable downstream. Now, I know we get charged with cost growth, and that is galling to some of us. But, on the other hand, I would invite you to the situation we would have if we went to individual, program-unique inflation rates. We tried that in the Air Force for awhile before OSD standard rates were invoked, and I'm not sure from the standpoint of equitable distribution of forces and resources that program-unique rates add any more to the process than having consistent rates applied across the board. Now, I'm not satisfied with the rates any more than some of the rest of you are; however, I think there is a virtue in uniformity. The other reason that I guess I'm concerned about addressing inflation in too much depth is that this is an area where we can fritter away literally thousands of man-hours on a marginally cost-effective basis. It's a popular subject to play with, but it's one that I fear has no real agreed solution. So, I'm in favor of adopting the standard rate and trying to improve the standard, but not encouraging everybody in the cost-estimating business to strike out on his own to decide what the proper rates would be.

Question: On that whole issue of inflation, I wonder if there isn't an alternative to forecasting inflation. Why not take inflation out of our budget altogether? Is there a possibility of considering budgeting in constant dollars and adjusting the actually appropriated dollars?

Response (Allen): The closest thing to that I've heard about came in the course of the Brooks testimony on weapon system cost growth. It surfaced as the discussion of inflationary forces showing up on the selected acquisition reports (SARs). Congress understands the cost growth on weapon systems attributed to inflation and there was a comment to the effect that maybe all of the SARs ought to be

done only in constant dollars so that the Congress could clearly differentiate cost growth attributable to inflation and cost growth attributable to non-macro economic forces. And, from time to time that has ebbed and flowed in terms of how to present that information. Currently, as you know, SARs are presented both ways, in both constant and current dollars, and at one time there were alternative inflation rate assumptions. But beyond that I have heard no proposal to talk of cost estimates only in constant-dollar terms. Obviously, you can't buy your program in constant-dollar terms. You can only buy your program in current-dollar terms, so we have to deal with those realities in the budgeting process.

Question: Regarding the challenges of the '80s, I suggest introducing some technological electronic network for the distribution of information among DOD sites similar to those for educational institutions. We find a network down in North Carolina between educational institutions for interchange of information programs. In Michigan, we find a network where universities interchange information, techniques, etc. When you can get on a system you can tap a different site having a different computer, and utilize its capabilities and its data base. What I wonder about in the electronic age of the '80s as we get more and more advanced in that era, is why we don't accelerate the interchange of information among the different services through a computer network for rapid transfer of information. I just throw that out and raise the question of whether there has been any thought toward that or should there be any?

Response (Morgan): Well, we have thought about that possibility with regard to data bases for different weapon systems. We would have in OSD a weapon system data base that could be made available to people in the field and we would have a link-up with the services so we all have access to the best possible data base master structure. Everybody could tap the data base. Now, there are some problems in that. First of all, one problem we have is getting money for studies in order to get something like this put together. We can't even get enough money to get our own data on a computer in OSD, and our study money has just been zeroed out by the Congress. We hope to get that back, but anyway, this is one problem—getting the dollar resources to be able to put something like that together. Second is the question of availability. Is the Army going to let us have all of their data base down at the Missile Command on missiles? Is the Air Force going to open up all of the Aeronautical Systems Division's data bases to OSD? These are some of the political questions. So, what you have described is an optimum situation; getting there is a problem.

Question: The last couple of days we have been hearing the theme of professionalism. What I would like to ask of the panel members is, is it time now for this discipline to initiate an American Society for Cost Analysis, publish a journal, and have dues-paying members?

Response (Allen): Well, I think in some respects we are moving along that line now. First of all, let me agree with Riner Payne—no one wants a cult. We are not interested in that kind of approach or thought process, but it does seem appropriate to talk in terms of a formal professional society. With that thought in mind, I suggest you may want to consider the National Estimating Society (NES) which is on the national level and has been in business now for 2 years. This particular society, the National Estimating Society, is principally made up of aerospace concerns. I'd say the mix in terms of membership is something like 90 percent industry and 10 percent government. But it does have the basic beginning of the type of thing you are getting at. There is the American Association of Cost Engineers, I believe, the specifics of which I'm not familiar with. When you stand back from this evolving process, the answer to your question is, yes, I feel quite sincerely we are ready as a profession and as a community to move along those lines.

Alternative Techniques for Use in Parametric Cost Analysis

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W. Eugene Waller
Thomas J. Dwyer

Cost analysts are plagued with many difficulties in trying to develop a cost estimating model or a point estimate for military systems. One of these difficulties is the limitations in the statistical procedures available to the practicing cost analyst. Another is the difficulty in developing cost models that are not made obsolete by the rapid advance of technology in military equipment. This paper describes (1) some alternatives to the conventional statistical methods of developing cost estimating models, and (2) a means for normalizing cost estimating models for technology advance so that these models remain relevant even though the technology is evolving rapidly. First, however, it is necessary to briefly describe the conventional method of cost analysis for those unfamiliar with this discipline.

Parametric Cost Analysis

The cost analysis discipline, as considered here, typically involves the development and use of parametric cost models or cost estimating relationships (CERs). These parametric models usually result from the application of multiple linear regression techniques to a sample of cost and technical information. The CER resulting from this process relates the dependent variable cost to technical performance variables of the system or other variables which impact cost.

Multiple linear regression allows one to fit a CER of the following form:

$$\text{Cost} = b_0 + b_1 X_1 + \ . \ . \ . + b_n S_n + \varepsilon$$

Where the X's are variables which impact cost, the b's are the fitted regression coefficients, and ε is an error (uncertainty) term. For example, a CER for the production cost of an RF transmitter might include average power and duty cycle as explanatory variables. There can be some flexibility in the specification of a CER. A CER of the following form may be fit using multiple linear regression:

$$\text{Cost} = b_0 X_1^{b1} \ . \ . \ . \ X_n^{bn} \ \varepsilon$$

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This is achieved by a logarithmic transformation of the dependent variable cost and the independent variables X and then application of the standard multiple linear regression technique.

The use of multiple linear regression produces various fit statistics such as R^2, standard error and t-statistics, which measure the goodness of fit and the uncertainty of the CER. These measures are often used in selecting the best CER from alternative CERs and in assessing the accuracy of the CER.

Parametric cost estimates are used in the early stages of a program, usually in concept formulation or in the research, development, test and evaluation (RDT&E) phase. This type of estimate is replaced later in RDT&E and production by projections of cost experienced in the program. Parametric estimates are only approximations; when there are only a few relevant programs, limiting the sample size, the number of variables that can be incorporated, in turn, are limited.

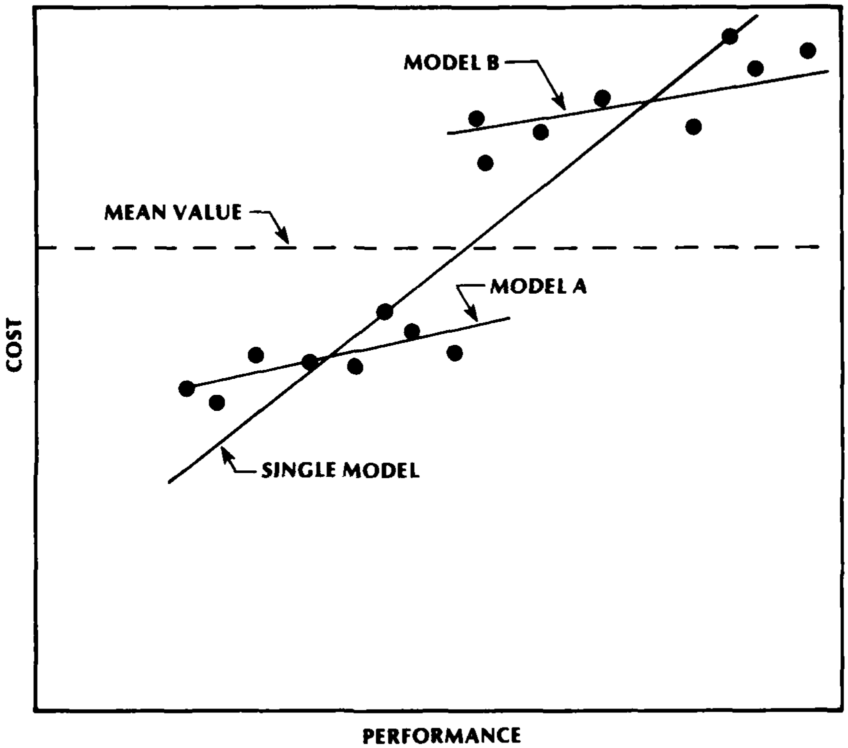
Model Selection Criteria

Frequently in cost analysis an analyst is faced with selecting among alternative specifications of cost models. How does one select the best model? All too often the criterion used for the goodness of the model is the R^2 value. The R^2 value, however, only describes how well the model explains variations in the data about the cost mean. A better measure of the goodness of fit in our view is the standard error of the model.[1] It is an important component (along with the variance of b coefficients) of the prediction interval. Minimizing the prediction interval is a primary concern of the cost analyst; consequently, achieving a minimum standard error should be a primary goal.

Minimizing the standard error and maximizing R^2 may lead to the same model. High R^2 values can be deceiving, however, because substantial error can still exist in the model as shown in the following example. Figure 1 exhibits a situation which sometimes arises in cost modeling. Cost data are available for a given type of hardware, e.g., rocket motors spanning a very wide range of performance. It is also known that the performance variable plotted in the figure is a cost driver. When all of the data are included in the sample, a deceivingly high R^2 is achieved in a single variable linear regression of cost against the performance variable because of the wide spread in cost values about the mean. If the cost data spans three orders of magnitude (leading to a high total sum of squares about the mean), an R^2 of 95 percent for the single model and a sample size as shown in Figure 1 will produce a standard error of about 30 percent, a significant

1. The standard error is the square root of the sum of squared residuals divided by the degrees of freedom. The square of the standard error is the best linear unbiased estimator of the variance of the error term of the model.

FIGURE 1
R^2 and Standard Error Comparison



estimating error. The figure reveals that a large proportion of the variation about the mean cost is explained by the single variable regression. It is apparent, however, that two different cost functions apply and that the standard error (variation about the line) could be reduced substantially by stratifying the data into two samples and fitting each one separately as shown in the lines labeled "Model A" and "Model B" in the figure. It is possible for the R^2 values of the stratified models to be less than the value for the single model even though the stratified model is a superior model. Admittedly, this is an extreme case, but just such a problem arose in a recent study where CERs were being developed for propulsion systems for strategic and tactical missiles. There, in a model of cost as a function of total impulse, it was necessary to stratify the sample by mission to produce the best model.

Another example of the use of the standard error in selecting a best model occurred in an evaluation of two different statistical approaches to measuring state-of-the-art advance (SOAA). The SOAA measure was included in an RDT&E cost estimating model for aircraft turbine engines as an independent variable, the cost hypothesis being that SOAA was a substantial determinant of RDT&E cost. The two different methods for measuring SOAA were evaluated based on (1) the RDT&E cost estimating model goodness of fit, (2) historical simulation results,[2] and (3) how well they estimated two programs that were not part of the data base used to quantify the models. The goodness of fit criterion used was the standard error of the two models. There was a considerable difference between each model's standard error (.11 vs. .14) even though the R^2 values were essentially identical (.970 vs. .972). The historical simulation results clearly confirmed that the model with the smallest standard error was the best model, as did a later exercise of estimating the two programs excluded from the data base.[3]

Non-Linear Fitting Techniques

Often in cost analysis, one develops a hypothesis about cost that cannot be fit to the data by conventional multiple linear regression techniques, e.g., Cost $= b_0 X_1^{b_2} + b_3 X_2^{b_4} + \varepsilon$. Usually the form of the cost function is then altered so that it can be fit. This is a second-best solution. A related problem is that a CER consisting of a sum of terms (e.g., $b_0 + b_1 X_1 + b_2 X_2$) cannot be fit conventionally where a multiplicative log normal error term is assumed. If fit assuming a linear error term, large cost programs dominate the result such that residuals (in percent of total cost terms) tend to be smaller for these programs. This is contrary to our perception of cost uncertainty and so it is desirable to have a means of fitting such a function with a log normal error term.

Two computer programs have been developed to handle these problems. While non-linear regression packages are generally available and could be used, these two programs are custom designed for particular needs. The first regression package (LOGFIT) allows only the limited non-linear capacity to fit cost as a linear function under the assumption of a multiplicative log normal error term. This mathematical form is frequently most appropriate in cost analysis. This package will also perform standard multiple linear regressions (including

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2. Historical simulation involves removing the most recent program from the sample, refitting the selected model form, and using the refitted model to estimate the deleted program.

3. C. A. Graver, *Historical Simulation: A Procedure for the Evaluation of Estimating Procedures*, General Research Corporation CR-0364-1, June 1969.

weighted regressions) and it also allows the incorporation of prior information (Bayesian statistics).

When other non-linear forms are required, a more general non-linear regression package is needed. This program (CRVFIT) is capable of fitting any smooth non-linear function using the linearization algorithm.

Many opportunities have arisen in our experience to use the LOGFIT algorithm to fit a sum of terms cost expression with a log normal error. One example of this occurred in a study of military software development costs. Software development costs are related to the number of machine words of storage developed for the system. It is also hypothesized that the cost per word varies with the type of software developed. In the study, "operational" (applications) software words were segregated from "development support" words. This latter category includes all non-operational software, i.e., simulation software, data extraction software, etc. Within the "operational" words category, "test" words were segregated from all other words.[4] The hypothesis to be tested was then:

$$\text{Cost} = (b_1X_1 + b_2X_2 + b_3X_3)\,\varepsilon$$

where

Cost = Software Development Cost (Total)
X_1 = Operational Words Other than Test
X_2 = Operational Test Words
X_3 = Development Support Words
b_1, b_2 & b_3 = Model Coefficients
ε = Error Term (Log-normal Distribution)

The coefficients that result from fitting this model are shown in Table I and are contrasted with the coefficients for the same model fit employing a linear error term. There is a significant difference between these two models, especially in the coefficients for the test and development support words.

TABLE I
Software CER Coefficients

	b_1	b_2	b_3
LOG NORMAL ERROR COEFFICIENTS	71	17	21
LINEAR ERROR COEFFICIENTS	56	10	40

4. Test words are words used for performance monitoring/fault location (PM/FL).

The software study also illustrates the use of the non-linear algorithm CRVFIT. This algorithm was applied to the following CER form:

$$\text{Cost} = b_1 X_1^{b_2} + b_3 X_2^{b_4} + b_5 X_3^{b_6} + \varepsilon$$

where all variables are defined as they were previously and six coefficients (b's) are fit.[5] The resulting coefficients are shown in Table II. One expects to see exponents closer to one, descriptive of linear cost behavior with words. This difficulty in interpretation led to the rejection of this model.

Bayesian Approach

In conventional parametric analysis, a homogeneous set of data is processed to establish the coefficients of the CERs. No prior knowledge of the CER is assumed in the classical least squares regression approach. However, the analyst may know, as the result of a previous study, the behavior and variance of the cost of an item, for example the planar array portion of a tracking antenna, yet have costs only for the complete tracking antenna including the gimbal system. This information, under a Bayesian approach, can be used to advantage where one is fitting a CER that consists of the sum of two terms, one term representing the planar array portion and the other the gimbal. The prior information will influence the coefficient on the array variable to be consistent with the prior data allowing better definition of the coefficient on the gimbal variable.

A regression program has been developed (tailored specifically to parametric cost analysis) which allows the incorporation of prior information into the CER development process.[6] This computer program allows the user to specify prior information about CER coefficients in terms of a prior expected value and a prior variance. The computer program then produces a least squares estimate by combining the prior information with the regression data set using Bayesian methods.

TABLE II
Software CER Coefficients (CRVFIT)

	b_1	b_2	b_3	b_4	b_5	b_6
CRVFIT COEFFICIENTS	**60**	**.97**	**38.6**	**.56**	**2.9**	**1.38**

5. This model is primarily shown for illumination since there are only 12 programs in the sample.
6. T. J. Dwyer, *Bayesian Methods—The Use of Prior Knowledge in Parametric Cost Analysis*, Tecolote Research, Inc. TM-70, March 1977.

As a special case of the above, the analyst can specify a prior variance of zero, effectively fixing the coefficient to the prior expected value. This can be a useful technique, especially with the small data sets which occur frequently in cost analysis.

An example of the application of the Bayesian approach to the development of a cost estimating relationship for radar tooling and test equipment is shown in Table III. A CER of the form $b_0 X_1{}^{b_1} X_2{}^{b_2} \varepsilon$ had been developed for missile tooling and test equipment cost in a prior study. The variable X_1 was the cumulative average cost for the missile and the variable X_2 was the peak production rate.[7] The value for the constant b_2 determined by the fitting process was .5. We had some confidence that the resulting CER was a good one. We believed that this constant would apply for radar tooling and test equipment as well. It is probable, for example, that a doubling of the peak production rate would not double the tooling and test equipment complement because of the opportunity for sharing some of the initially purchased equipment by the second production line. This rationale led to the incorporation, in the fitting process, of the prior missile study information on the expected value and the standard deviation of the coefficient b_2.[8] Regression coefficients and statistics for this fitting, together with the same statistics for the run without the prior information is shown in Table III. In this

TABLE III
Comparison of CER Results With and Without Use of Prior Information

	Coefficient	t-Value	Prior Mean	Prior Standard Deviation
MODEL 1				
ln b_0	1.580	5.97		
b_1	1.000	∞	1.000	0.00
b_2	.482	2.78		
MODEL 2				
ln b_0	1.568	6.93		
b_1	1.000	∞	1.000	0.00
b_2	.493	4.53	.500	.140

7. b_0, b_1 and b_2 were constants.
8. This information is produced in every regression run.

particular instance, the effect of the constraint is quite small, adjusting the b_0 and b_2 values only slightly. Either model could be employed. The higher t-value on b_2, however, reflects the greater certainty that b_2 is not zero because of the prior data. It also yields a narrower prediction interval for a point estimate. In general, more dramatic results than shown here can be expected.

This example also shows another application of the Bayesian technique. The value of b_1 has been limited to 1.0 without deviation, i.e., the dependent variable is a linear function of X_1, cumulative average cost. This is a common requirement in cost analysis that can be handled conventionally by transforming the dependent variable; however, employing the Bayesian approach facilitates the process and also provides fit statistics for the variable of interest, cost, not some transformed variable such as the ratio of tooling and test equipment cost to cumulative average cost.

Fitting Learning Curves

While learning curves may be the most discussed subject in cost analysis, there are a few subtle difficulties that deserve attention. The difficulties are not with learning curve theory itself, but with the problems involved in actually fitting a learning curve to historical data.

There are a variety of learning curve theories, all of which state that unit manufacturing costs drop as more units are produced. The two most popular formulations are:

1. $UC = AQ^b$
   where UC is the cost of the Qth unit, and A and b are constants.
2. $CAC = AQ^b$
   where CAC is the cumulative average cost of the first Q units, i.e., CAC is the total cost of the first Q units divided by Q and A and b are constants.

The constant A is usually termed the Theoretical First Unit Cost and the constant b is the slope, although the slope is usually given in percent (100×2^b).

The practical difficulty with equations 1 and 2 is that, statistically, the model has not been completely defined because these equations lack specification of the error term. When completely specified, these two equations can produce a variety of models, four of which are given below.

1.a $UC = AQ^b$ [illegible]
   where US is the cos[illegible] Qth unit.

1.b $LAC = AN^b\ \varepsilon$
   where LAC is the lot average cost and N is the unit theory lot midpoint.

2.a $CAC = AQ^b\ \varepsilon$
   where CAC is the cumulative average cost of the first Q units.

2.b $LAC = AM^b\ \varepsilon$
   where LAC is the lot average cost and M is the synthetic cumulative

average theory lot plot point,[9] and in all the equations ε is a lognormal error term.

Of these above equations, equations 1.a and 1.b are unit theory equations corresponding to equation 1, and equations 2.a and 2.b are cumulative average theory equations. Notice the differences in the dependent variables among these equations.

Statistically, all these equations are distinct, although in the case of perfect data (i.e., no noise) equations 1 will agree and equations 2 will agree. Furthermore, there can be no statistical comparison between how well the unit theory equation 1.a fits the data as opposed to the cumulative theory 2.a because the dependent variables in these equations are so radically different. There can, however, be a goodness of fit comparison between equations 1.b and 2.b.

The differences between the equations can be stated non-technically in terms of the implied weighting each equation gives to each data point. Equation 1.a gives equal weight to the cost of each unit. However, this equation can seldom be used in practice because most military equipments are bought in lots of a quantity greater than one, and hence the cost of individual units is not available. In this case, the unit theory analyst usually turns to equation 1.b where each lot is given equal weight. But, in comparing 1.a to 1.b, individual units which belong to larger lots are given less weight than would be implied by equation 1.a.

Equation 2.a (which is the usual cumulative form used in practice) has the most pronounced weighting among the four equations since the dependent variable (CAC) is calculated as the quantity-weighted average of successive lots. This implicitly weights early lots more heavily than later lots. Like equation 1.a, this equation is also difficult to use in practice because its use requires that the cost of each successive lot be known. For example, if the cost of the first lot is unknown (or perhaps contaminated in some way) this equation cannot be used even if a good history is available for succeeding lots. However, it can generally be used more often than equation 1.a.

Equation 2.b is similar to equation 1.b and hence the weighting is the same, allowing a statistical comparison between 1.b and 2.b.

To cope with these choices, a computer program has been developed which by iteration can fit all four model choices to the data (subject to the restriction on equations 1.a and 2.a). This forces a comparison of the four equations although we typically use either 1.b or 2.b which generally give similar results.

An example of this comparison for a missile seeker is given below.[10] Notice that the results are quite different for equations 2.a and 2.b although they are both based on the same equation, differing only in how the equation is fitted to the data.

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9. *The point at which the lot average cost is equal to the cumulative average cost.*
10. Equation 1.a could not be fitted because lot sizes were greater than one.

MISSILE SEEKER

	A	Slope	Standard Error
EQUATION 1.b (Unit Theory)	**11.0**	**95.5%**	**.18**
EQUATION 2.a (Cumulative Theory)	**17.8**	**92.3%**	**.04**
EQUATION 2.b (Cumulative Theory)	**11.8**	**95.5%**	**.18**

As the example shows, the different equations can produce very different results. Notice that equation 2.a, by averaging lot costs, has smoothed most of the variation out of its dependent variable as is reflected in the standard error.[11] In fact, the use of equation 2.a has served to obscure cost trends in the most recent lots. In this example, the learning curve in later lots began to flatten out. Because equation 2.a weights early lots most heavily, this flattening was ignored. The consequence of this is that future lots would probably be seriously underestimated by equation 2.a, while the other equations, which are responding to the changing trend, would produce good estimates.

Technology Advance

Technology advance has always troubled military systems cost analysts. Creation of a large enough sample for CER development usually involves including equipment that was introduced up to 10 or more years ago. Most technologists in the electronics industry consider that era to be ancient history and irrelevant to current technology. But there is value to that old information. It may help in quantifying the underlying cost function if the effect of technology advance can be removed, i.e., if the data can be normalized for the advance.

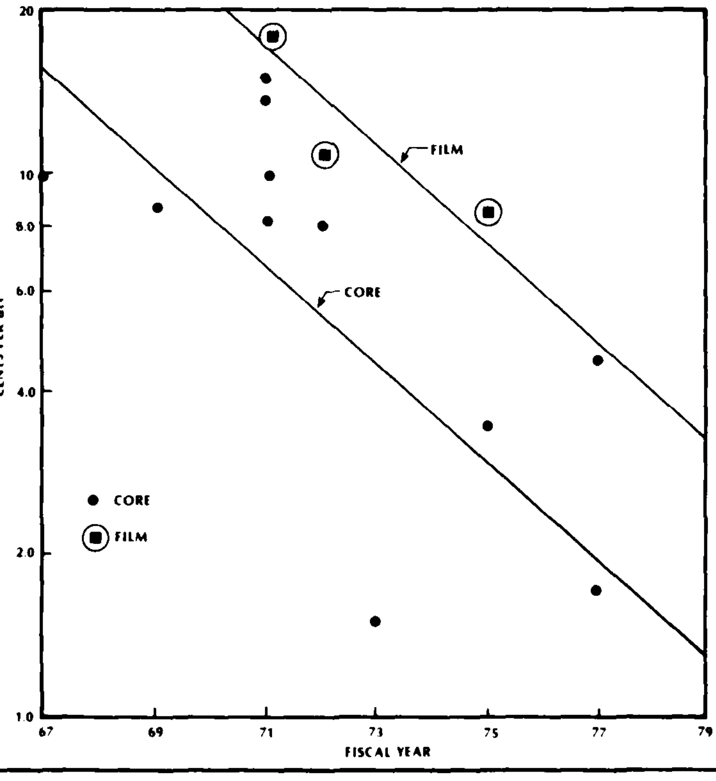
One method that has been used to accomplish this is to incorporate, in a log-normal linear regression, a term (b_nX) called a "technology index," where X is a calendar year variable corresponding to the year of initial manufacture of the particular item, and b_n is the regression coefficient. This term, assuming b_n is negative, acts to adjust the resulting CER downward at a continuous rate year-to-year thus capturing, in an approximate way, the continuing advance of technology. This specification of the cost function hypothesizes that technology advance proceeds at a uniform rate over a long period of time. One may argue that technology advance is discontinuous, occurring in large, discrete jumps;

11. Note that the standard errors are not comparable, and hence the standard error does not indicate that equation 2.a is superior.

however, new technology is usually implemented in military hardware in a much more gradual way. Take, for example, solid state RF amplifiers. Although these have been available for a long period of time, final power amplifiers for virtually all radars are electron beam tubes. There has been some penetration by solid state amplification at lower power levels, e.g., as drivers for final amplifiers or for amplification at lower frequencies, but this has been a gradual process.

An example of the incorporation of a technology index in a CER is shown in Figure 2 for core and magnetic film memory. Cost per bit are plotted vs. year first manufactured. The steep downward slope of this cost function, with fiscal year, is the result of the technology index adjustment. The technology index shown reflects a 17-percent-per-year reduction in cost per bit. Technology indices like

FIGURE 2
CER for Core and Film Memory



these have been established in other areas including SAW devices, A/D converters, and signal processing.

The use of extraneous or prior information on technology advance would seem to be an ideal application of the Bayesian approach. A number of functions similar to Figure 2 have appeared in the digital electronics literature presenting a possible source of prior information on technology advance that could be incorporated with the sample data.

Conclusion

This paper has described some of the methods helpful in analyzing cost data for military systems. These methods alleviate a number of the difficulties an analyst is faced with when estimating costs. The Bayesian approach allows the analyst to benefit from prior information on cost behavior. Non-linear methods give the analyst a wider and often more appropriate set of mathematical forms to choose from when developing CERs. The incorporation of a technology index in a CER is a means for compensating for technology advance and its adverse impact on CERs. Finally, alternate means of fitting learning curves provide the analyst with increased flexibility and better visibility in the assessment of the true behavior of cost with quantity. The proper use of these tools should lead to better CERs permitting the analyst to focus his attention on some of the other formidable problems of cost analysis.

MX Cost Analysis

60

Major Donald E. Crawford, USAF

In 1976 the MX missile program office designed a computerized cost model that recognized that: (1) MX estimates would be based on other solid-fuel missiles, but historical data would be limited; (2) MX would be one of the largest procurements ever attempted by the U.S. Air Force; (3) the cost data would be subjected to intense scrutiny from many sectors; and (4) numerous changes would occur during the procurement, requiring immediate repricing of the estimates.

I will attempt to provide a background and a general description of the computer model developed. My description is divided into major components for ease of understanding; however, all applicable costs are calculated and produced in one computer product, providing a true life-cycle cost model sensitive to changes in concept that affect either acquisition or operation and support.

The concept for a Minuteman follow-on missile began officially with a program management decision dated June 11, 1973, which directed Defense Systems Acquisition Review Council (DSARC) I for January 1976. That DSARC I milestone presented the following basing possibilities: vertical shelter, buried trench, air mobile, and Minuteman-silo basing. The number of missiles to be placed on [illegible] in each of these systems varied significantly; therefore, the costs of the differen[illegible] ptions could not be directly compared.

For DSA[illegible] II, the program office was directed to concentrate on ground-based option[illegible] only. The first DSARC II briefings in late 1978 presented the following opti[illegible]s: MX in vertical shelter, MX in horizontal shelter, and MX in buried trench. The two missiles proposed were 92 inches and 83 inches in diameter. Some basing models included installation of missiles in existing Minuteman silos with later moves scheduled to Southwest bases. As a result of this series of briefings, the program office was directed to concentrate its efforts on evaluating the air mobile MX. There was no aircraft specifically designed to perform this mission; therefore, modifications of the AMST, Boeing 747, and C-5, with seven missiles of varying weights, were considered and estimated. These studies were completed in March 1979 and, although the 92-inch-diameter missile was selected, the available system was considered too highly technical and costly to deploy.

In early 1979 another study was made of the basing mode with emphasis on those requirements that would result from congressional approval of the SALT II treaty. The horizontal shelter and buried trench were emphasized owing to the difficulty of verifying the presence of missiles in vertical silos. The added view-

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ports in the top of the shelters for both options provided easy verification of those missiles among the shelters. Because of costs and technical issues, the horizontal-shelter option was selected and work continued on refining both concepts and cost estimates.

In the spring of 1980 the concept of elliptical paths, each having 23 shelters, was deleted because of excessive construction costs, and a grid network was substituted. In addition, the spacing between the shelters was reduced. The net effect of these changes was an increase in procurement funds and a decrease in construction funds. The design and cost estimating of this option are still ongoing.

In addition to these major exercises, the program office completed approximately 60 life-cycle cost estimates between July 1979 and December 1980. To accomplish these studies within limited time frames, a complete and flexible computerized cost model was used.

MX Optimization Cost Model

The number of missiles required for the MX system is established, based on the threat applicable in the year of the system's initial operating capability (IOC). Thus, the threat is one of the key inputs to the model and, when coupled with assumed reliability of the system, provides the number of missiles available for launch after the attack. The amount of surviving megatonnage was established prior to design of the system.

The program designs the system with trade-offs for spacing, hardness, and other variables, and produces a least-cost solution to meet the specified threat. To do this the computer program must contain information on the unit cost of various items.

Research and development costs (3600) are through-put to the model because no variations owing to changes in the number of units were known or anticipated. These factors are the same as those used by the model for optimization; therefore, it is not necessary to have the model estimate them.

Investment costs are key to the optimization and formed the basis for the entire model. Non-recurring costs are estimated off-line and through-put. Recurring costs are estimated by the model.

The first unit cost and learning-curve slope for each procurement item is calculated off-line using cost-estimating relationships, engineering buildup, or a combination of both. Construction costs for more than one type of shelter are estimated, utilizing subroutines that, in effect, design the shelter. The subroutines, given the spacing requirements, determine the hardness of the shelters and the miles of road required. Requirements for various materials, labor, and earth moving are calculated and converted to costs using appropriate factors.

After the number of missiles, required manpower, number of shelters, and locations have been determined, the operating and support costs are calculated, and the computer program minimizes costs through trade-offs between numbers of misssiles, shelter hardness, and spacing between shelters.

To minimize cost, the gradient projection method devised by J. B. Rosen is used in the model.[1] Rosen's technique modifies the method of steepest descent to permit linear constraints, while allowing a non-linear objective function. The method consists of first finding a feasible point, calculating the gradient of the cost function at that point, and then taking a step along the steepest gradient. The length of the step is the maximum permitted by the physical structure of the cost surface and constraints. If the step falls outside the feasible region, modifications are performed to return it to the feasible region. Using this method, convergences to the minimum are usually quite rapid; however, some pathological surfaces will fail to converge or converge very slowly unless the starting point is chosen with care.

Through use of the model, requirements for the MX missile system have been derived in a manner unique to weapon systems acquisition. The requirements are determined by a specified threat, the threat is quantified, and the number of missiles required to counter that specific threat is provided. The supporting infrastructure for the weapon system has been constructed to require the least life-cycle cost. Thus, through computer modeling, we have been able to provide timely and defensible cost estimates on many proposed MX basing and launching modes.

1. J. B. Rosen, "The Gradient Projection Method for Nonlinear Programming, Part I: Linear Constraints," *Journal of the Society for Industrial and Applied Mathematics*, 9:1 (1960), pp. 181-217.

63 Redistributing Fixed Overhead Costs

Commander Steve J. Balut, USN

When reviewing Five Year Defense Plan (FYDP) updates submitted by the services, we in the Office of the Secretary of Defense (Program Analysis and Evaluation) consider alternatives to proposed aircraft procurement quantities and rates. Costing the alternatives involves deriving new average unit prices for each lot consistent with new lot quantities, and then adjusting prices to reflect the attendant redistribution of fixed overhead resulting from the change in production rate. This article focuses on the second part of the calculation, which we refer to as a "rate adjustment."

The reason for shifts in overhead are not well understood, and predicting these shifts has involved more art than science. This office takes a first cut at rate adjustments using a heuristic model that has evolved over the years.

This paper evaluates that model by comparing its predictions to actual contractor experience, and then presents an improved model derived using contractor data. Use of the new model is illustrated with several examples. Finally, a number of possible extensions to this research are suggested.

Background

During FYDP development and review, we are frequently asked to estimate the cost of alternatives to aircraft procurement program quantities and production rates proposed by the services. We usually base our estimates on detailed cost sheets submitted by the services, along with their FYDP updates. These sheets display the prices the services say they will pay if the program is approved.

We in OSD(PA&E) generally develop our estimates in two steps:

—Adjusting the service estimate for quantity change;

—Adjusting for rate change.

The first step is straightforward and involves developing a program price curve, at the recurring flyaway level, and repricing the new lot quantities, accounting for movements up or down the learning curve.

The second step in making the estimate is more difficult. The adjustment for rate change involves a redistribution of indirect charges at the plant, a portion of which varies with activity rate, and a portion of which doesn't. Examples of "variable overhead" costs include employee benefits, payroll taxes, and other

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production-related indirect costs that are tied to the number of direct laborers working in the plant and the number of units being produced. On the other hand, costs that do not vary with activity rate and are fixed in the short term are usually referred to as "fixed overhead." Examples include depreciation and amortization, insurance, rent, and security.

Unfortunately for the cost analyst, there are some indirect expenses that don't fall neatly into either of the above categories, since they are partially fixed and partially variable. We refer to these as "semi-fixed overhead." An example is utility expenses. Lights are turned on and environmental conditions maintained at some minimum level independent of the activity rate (above zero) in the plant; however, use of such things as electricity, heat, and air conditioning increases with production rate. Utility costs (and other such semi-variable overhead expenses) are gathered and reported as pools and, because of this, the fixed and variable portions are not discernible.

The open literature contains very few references to overhead cost-estimating methods. Gross and Diennemann used statistical methods to show, for the aerospace industry, that total overhead costs were 62 percent variable with respect to direct labor dollars and 46 percent variable with respect to direct labor plus material.[1] Hurta shows standard labor dollars as the best volume measurement for a cost center, and presents two relationships between overhead costs and standard labor dollars for use in estimating overhead cost.[2]

Other documents provide definitions of overhead cost categories, provide guidance for monitoring such costs, and discuss the relationship between cost accounting and price.[3] Two references present interesting overhead cost management techniques. The first proposes a sharing arrangement for overhead cost underruns and overruns of advanced agreement targets.[4] The other presents a method for allocating overhead charges on the basis of a mathematical program-

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1. S. Gross and P. F. Drenemann, "A Model for Estimating Aerospace Industry Contractor Overhead Costs," *Engineering and Process Economics 3* (1978): 61-74.

2. N. W. Hurta, "Analysis of Overhead Cost for a Defined Cost Center in the Lake City Army Ammunition Plant Using Regression Analysis," Army Material Command , Texarkana, Texas, Intern Training Center Report May 1974.

3. Air Force Test and Evaluation Center, *Cost of Ownership Handbook* Kirkland AFB, N.M., May 1976; ASD(I&L), *Guide for Monitoring Contractor's Indirect Cost*, July 1974; LMI Report, Guide for Monitoring Contractor's Indirect Cost, December 1973; and C. E. Jarrett, "An Examination of the Interface Between Cost Accounting Standards and the DOD PIECOST Project in Solving Government Contractor Overhead Cost Problems," Master's Thesis, George Washington University, September 1971.

4. P. J. Lynch and J. M. Pace, "An Analytical View of Advanced Incentivized Overhead Agreements in the Defense Industry," Master's Thesis, Air Force Institute of Technology, September 1977.

ming model for production and sales possibilities.[5] The basic scheme is to charge products on the basis of their use of scarce resources of the firm (charges being the value of the dual variables of the profit-maximizing mathematical program).

When making our estimates, we treat overhead statistically, not functionally. In this way, we do not get bogged down with allocation schemes for splitting semi-variable overhead pools. Instead, we observe changes in total overhead expenditures associated with changes in activity rate within the plant, and use these observations as guides for the future. Application of this experience has evolved over the years into the form of a mathematical model that we refer to as a "rate adjustment" model.

It is important to note again that we develop our estimates in two steps. The first involves the standard use of learnng curve theory,[6] the application of which, at the price level, involves an implicit assumption that overhead is 100 percent variable with direct costs. Our second step corrects for this erroneous assumption as application of the rate adjustment model (to the estimate derived in step one) accounts for the redistribution of fixed overhead across the new activity levels within the plant. (See following page.)

5. R. S. Kaplan and G. L. Thompson, "Overhead Allocation via Mathematical Programming Models," Management Sciences Research Group Report, Carnegie-Mellon University, December 1970.

6. G. Fisher, "Cost Considerations in Systems Analysis," RAND Report R-490-ASD, December 1970, and "Military Equipment Cost Analysis," Prepared for OSD(SA) by the RAND Corporation, June 1971.

The model is:

$$F_i = \left[\frac{Q_i^{\text{Old}}}{Q_i^{\text{New}}}\right] PR + (1 - PR)$$

Where i = lot number:

F_i = The factor used to adjust the estimate for lot i derived in step one.

Q_i^{Old} = The quantity of aircraft in lot i in the basic service program.

Q_i^{New} = The new quantity for lot i in the alternative program.

P = The fraction of price represented by overhead.

R = The fraction of overhead that is fixed in the short term.

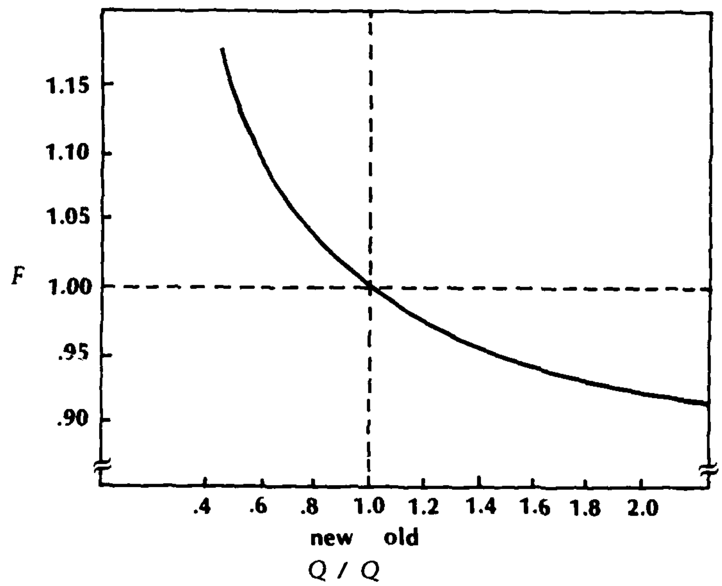
The product PR represents the fraction of price represented by the overhead fixed in the short term. Lot quantity is used as a proxy for lot direct cost. When the new quantity (associated with the alternative program) is greater than the old quantity, the ratio $Q_i^{\text{Old}}/Q_i^{\text{New}}$ is less than one, resulting in a factor F_i less than one. When applied to the estimate developed in step 1, the factor reduces unit cost by spreading fixed overhead over a larger quantity. When the new quantity is less than the old, the opposite occurs.

The values used for P and R, .35 and .42, are estimated aerospace industry-wide averages derived by this office about 2 years ago.

Figure 1 shows a graph of the factor F_i as a function of the ratio $Q_i^{\text{New}}/Q_i^{\text{Old}}$. This unit of measure is chosen for the x-axis because it allows direct reading of the percentage increase or decrease of the new quantity with respect to the old.

Our experience indicates that rate adjustment made using this model are good when the ratio $Q_i^{\text{New}}/Q_i^{\text{Old}}$ is near unity; however, our confidence decreases

FIGURE 1
Old Rate Adjustment Model



rapidly as the ratio deviates from unity. We have applied the model to make first-cut estimates, cautiously, when the ratio remained within the limits:

$$.5 \leq \left[\frac{Q^{\text{New}}}{Q^{\text{Old}}}\right] \leq 2.0$$

When quantity changes varied more drastically than that, other methods were used.

Reservations about the accuracy of this model led to the analysis reported in this article.

Contractor data were collected for two purposes:

—To compare model predictions with actual contractor experience, and

—To use the data to develop an improved model.

The next several sections report the results of the data-gathering effort, old model evaluation, and new model derivation, followed by several examples that illustrate its use. Then the limits of applicability of the model are discussed, followed by the presentation of a number of promising extensions to this research effort

Data

Data was extracted from contractor cost data report (CCDR) plant-wide data reports (DD Form 1921-3). To date, only three contractors all manufacturers of fighter/attack aircraft, have submitted reports containing data suitable for analysis. The 1921-3 report presents annual overhead charges associated with contractor-reported annual business bases. (The reported business bases generally correspond to actual business bases; however, there are indications that they may differ by 1 or 2 percent in some instances, due to lack of uniformity among contractors on how the base is described.) The reports used in this analysis present business base and overhead for years 1975, 1976, and 1977, and projections for 1978, and in one case, beyond 1978.

For purposes of this analysis, cost elements were aggregated into the following categories:
—Direct labor
—Direct material
—Indirect labor

TABLE 1
Cost Breakdown (Percentages)

	Contractor			
	1	2	3	ALL
Direct				
Labor	20	17	24	19
Material	41	40	50	43
Total	61	57	74	62
Indirect				
Labor	25	30	14	25
Material	3	3	4	3
G&A	11	10	8	10
Total	39	43	26	38

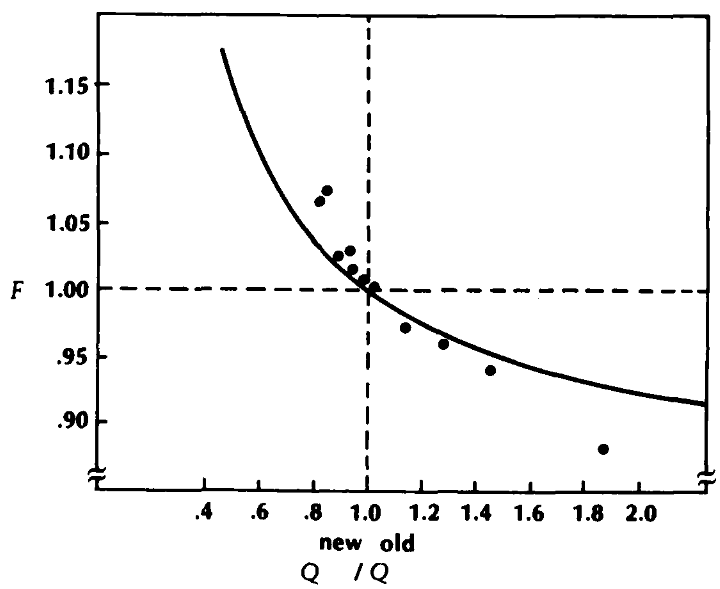
—Indirect material
—General and administrative (G&A)
In this analysis, the term "cost" refers to the sum of direct and indirect costs plus G&A expense. The term "price" refers to cost plus fee, where fee is estimated to be 11 percent of the sum of all categories shown above, less direct material. When making cross-year comparisons, all data were reduced to 1975 dollars using OSD(C) procurement escalation indices.

Table I shows a summary cost of breakout by contractor. The numbers in the table represent percentages of total cost.

Data in this sample indicate that, for the prime contractor:
—Overhead represents about 38 percent of cost.
—Labor overhead is about 132 percent of direct labor cost.
—Material overhead is about 7 percent of direct material cost.

This analysis indicates that cost represents about 94 percent of price, the remainder being fee.

FIGURE 2
Old Rate Adjustment Model Compared to Actual Data



Old Model Compared to Data

Figure 2 presents a graph of the data, along with the graph of the model. Eleven data points were obtained, one very close to the point where QNew/QOld equals one, five to the left of that, and five to the right. The range of the sample is

$$.83 \leq \left[\frac{Q^{\text{New}}}{Q^{\text{Old}}}\right] \leq 1.85$$

representing from a 17 percent reduction up to an 85 percent expansion in direct business. The plot indicates that the model has approximately the right curvilinear form, but the wrong slope. According to this sample, our model tends to underestimate the effect of reductions in activity rate on per-unit overhead costs, and overestimates the effect of expansions.

Improved Rate Adjustment Model

It was clear from the start that the model could be improved by adding an exponent to the ratio term as follows:

$$F_i = \left[\frac{Q_i^{\text{New}}}{Q_i^{\text{Old}}}\right]^b PR + (1 - PR)$$

where all variables are as defined earlier, and exponent b has been added. We have, in simplified form:

$$y_i = a \; x_i^b + (1 - a)$$

A non-linear curve-fitting routine was applied with the following results:

Coefficient	Fitted Value	Standard Error	T-Statistic
a	0.162	0.043	3.76
b	-1.669	0.54	-3.1

This form produced very favorable statistics: an adjusted coefficient of determination (R^{-2}) of 0.95, a standard error of estimate (SEE) of 0.012, and a Durbin Watson statistic (D-W) of 2.46. Table II compares actual and predicted values for the dependent variable.

The predicted values differ from the actual values at worst by less than 2 percent, and on the average are about 1 percent off. Figure 3 shows a graph of the model, along with the plotted data, and also a trace of the model shown in Figure 1.

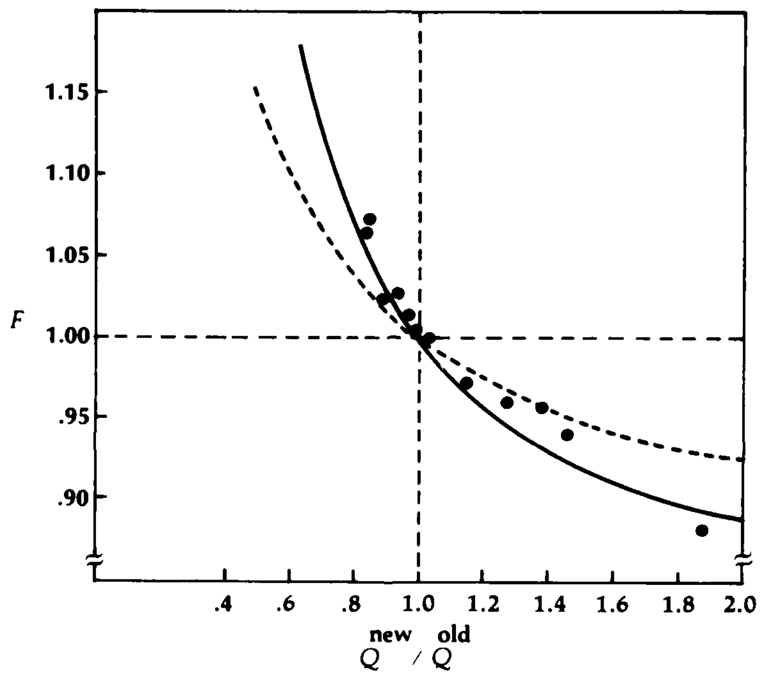
Coefficient "*a*" stands for the product *PR*, the fraction of price represented by overhead that is fixed in the short term. Analysis of contractor data revealed that *P*, the fraction of price represented by overhead, is about 0.36. The data also imply, via the least-squares, curve-fitting routine, that coefficient *a*, and therefore, product *PR*, equals 0.162. This implies that *R*, the fraction of overhead that is fixed in the short term, equals about 0.45. These results compare favorably with the findings of an undocumented study done by this office 2 years ago in which aerospace industry-wide averages for *P* and *R* were estimated to be 0.35 and 0.42, respectively.

TABLE II

Comparison of Actual Data With Model Predictions

	Y		%
X	Actual	Predicted	Deviation
.831	1.056	1.059	+ .25
.848	1.072	1.051	−1.97
.904	1.023	1.030	+ .65
.929	1.026	1.021	− .47
.960	1.014	1.011	− .25
.994	1.005	1.002	− .34
1.035	1.000	.991	+ .91
1.153	.970	.966	− .44
1.280	.962	.945	−1.77
1.463	.940	.924	−1.75
1.847	.881	.896	+1.72

FIGURE 3
New Rate Adjustment Model



Examples

The use of the rate adjustment model is illustrated here with two simple, contrived examples. The first illustrates the technique when the contractor has only one program. The second example shows the modification necessary when the contractor has other ongoing programs.

Data for example 1 are shown in Table III. Line one indicates that the basic program has a level production rate of 10 per period, and the alternative program, indicated by line two, specifies a proposed reduction in the first lot quantity from 10 to 8, and an increase in the third lot quantity from 10 to 15. The estimates of unit recurring flyaway prices for the new lot quantities, assuming overhead is 100 percent variable with direct costs, are shown in line three. (Derivation of these

TABLE III
Data for Example 1

		LOTS		
Line	Description	1	2	3
1	Old program *Q*	10	10	10
2	New program *Q*	8	10	15
3	Estimated avg unit recurring flyaway price (without rate adjustment)	11	10	9
4	Rate adjustment factor	1.073	1.0	.920
5	Estimated avg unit recurring flyaway price (after rate adjustment)	11.8	10	8.3
6	Adjusted recurring flyaway price	94.4	100	124.2

estimates is not addressed in this paper.) Line four shows the rate adjustment factors derived using the model

$$F_i = .162 \left[\frac{Q_i^{\text{New}}}{Q_i^{\text{Old}}} \right]^{-1.669} + .838$$

Line five is the product of lines three and four, and represents the average unit recurring flyaway price after adjusting for change in rate. The last line is the product of lines five and two, and represents the recurring flyaway prices of each lot.

For lot 1, a 20 percent reduction in production rate leads to about a 7 percent increase in unit price due to redistribution of fixed overhead. For lot three, a 50 percent increase in rate leads to an 8 percent decrease in unit price.

The data for example 2 are shown in Table IV. In this case, we assume the contractor has other ongoing programs which contribute to his business base. The other programs must be taken into account when redistributing fixed overhead. The procedure is similar to that used in example 1, with the exception of the

TABLE IV
Data for Example 2

		LOTS		
Line	**Description**	**1**	**2**	**3**
1	Old program Q	10	10	10
2	Equivalent units of other business	5	10	15
3	Old rate (in equivalent units)	15	20	25
4	New program Q	8	10	15
5	New rate (in equivalent units)	13	20	30
6	Estimated avg unit recurring flyaway price (without rate adjustment)	11	10	9
7	Rate adjustment factor	1.044	1.0	.957
8	Estimated avg unit recurring flyaway price (after rate adjustment)	11.5	10	8.6
9	Adjusted recurring flyaway price	91.9	100	129.3

derivation of the ratio, Q^{New}/Q^{Old}, used in the model. In example 1, we allowed program quantities Q^{New} and Q^{Old} to represent old and new production rate. In example 2, we translate the contractor's other direct business into equivalent units[7] of the article being priced, and add these annual subtotals to both Q^{New} and Q^{Old}. Now the ratio captures the change in total contractor activity level resulting from a change in our program:

$$\frac{Q^{New} + \text{Equivalent units of other business}}{Q^{Old} + \text{Equivalent units of other business}}$$

7. Divide other direct business by the unit price of the product being considered.

The data for example 2 in Table IV are essentially the same as for example 1, but a few more lines have been added. Line two shows the number of equivalent units of other business. This is added to lines one and four to arrive at old and new rates, in equivalent units, as shown in lines three and five. The ratio of these figures is entered into the model to arrive at the rate adjustment factors shown in line seven.

Note that redistribution of fixed overhead over a large business base results in a smaller adjustment than seen in example 1. A 20 percent decrease in our program leads to about a 4 percent increase in unit price, as compared to about 7 percent in example 1. For lot three, a 50 percent increase in our program leads to about a 4 percent decrease in unit price, as compared to about 8 percent in example 1.

The data used to develop the model presented in this paper relate to fighter/attack airframe manufactures. Applying the model at the flyaway price level involves an implicit assumption that the shift in business base will affect propulsion and avionics contractor costs (that can add up to about 48 percent of flyaway) in a manner similar to the effect on the airframer's costs. In cases where the engine and/or avionics manufactures have much larger business bases, as compared to the airframers, the effect of program quantity changes could be made separately for each major contractor. In any event, the model should be applied with caution, and then only within the range of data supporting its development ($.83 \leq Q^{New}/Q^{Old} \leq 1.85$).

Extensions

The direct and immediate extensions to this research are plentiful. I will mention but a few.

OVERHEAD DATA

The plant-wide data report (CCDR Form 1921-3) is the only known comprehensive source of overhead expenditures by defense contractors, aside from reports received by the Defense Contract Administration Services (DCAS), some irregular government audit reports, and actual visits to the contractors. The requirement to submit the 1921-3 report has been in effect only a few years. There are no reports covering the period before 1975, and little more than a handful covering 1975 to the present. This probem will be overcome as more and more reports are received; however, there exists a fundamental problem with data consistency between reporting contractors. Review of reports at hand reveal major inconsistencies, including:

—All contractors report plant-wide data, with the exception of one, who submits separate reports on each program at the plant.

—Some contractors include material costs in the overhead base and others exclude them.

—Some contractors use one set of cost categories when reporting historical costs, and another in their projections.
The 1921-3 report format and reporting procedures need to be firmed up and enforced, or the value of the data received on these reports will be seriously degraded.

EXTEND THE MODEL DATA BASE

Only 11 data points were used to develop the model reported here. Confidence in the model could be improved, and its range and applicability could be extended, if more data points were obtained. As additional data is developed, separate models could be derived for cargo aircraft, helicopters, missiles, space vehicles, and perhaps even tanks and ships. In addition, we need to look carefully at the characteristics of engine manufacturers and avionics manufacturers. When sufficient data are available, separate models can be derived from each major defense contractor.

DEVELOPMENT PROGRAM OVERHEAD COSTS

Overhead costs associated with development programs are less well understood than those for production programs. Some original thought should be given this area. It seems, at the very least, that a review of recent development program costs would reveal the relationship between direct and indirect costs during development.

REPRICING MODEL

If our rate adjustment model were coupled with a learning curve routine, the combination could perform the two steps in repricing a new program quantity stream in an efficient and consistent manner. This "repricing model" is simple enough to be programmed on a hand calculator. ‖

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Effect of Production Rate on Weapon System Cost

Dr. Charles H. Smith

Recent experience has shown that production rates for new military weapon systems are subject to continual adjustment during both the planning and production phases. Yet the impact of these rate changes on unit costs is not generally understood. The learning-curve concept, which estimates unit cost as a decreasing function of cumulative production quantity, is heavily used in cost estimating. Seldom, however, are adjustments made to reflect the impact of different production rates. This paper addresses the current state of production rate research and proposes a technique applicable to future weapon system cost analysis.

We must remember that factors other than cost must be given weight in production rate decisions. For example, rate decisions affect deployment and readiness; having a tank available this year is not the same as having it available next year. Training and logistics factors also must be considered. Unlike most commercial production, the typical weapon system is designed for a build-up to high quantity production for a relatively few years. Typically, follow-on production will then continue, but at much lower rates, which is one reason that excess capacity often exists.

Affordability issues also prevent the viewing of production rate as an isolated cost optimization problem. Affordability issues arise from an overall constraint on annual spending. This constraint, combined with large numbers of competing programs, causes production stretch-outs and other adjustments. Military preparedness may thus dictate that almost no system can be produced at rates that would be most efficient. Factors leading to development of a production plan are sketched in Figure 1.

Although the reasons for a particular production plan may seem convincing, a complete cost analysis requires an estimate of the unit cost effect of alternative production rate schedules. While an unlimited variety of program circumstances exist, the rate problems fall into two basic classes. The division is based on whether or not the system under analysis is past the preproduction planning stage. The two situations present different factors with which t[illegible] concerned, for flexibility is hampered once manufacturing facilities are on[illegible] and workers are hired. Moreover, the first problem—the planning pr[illegible] marily concerned with the cost over the entire production life [illegible] program. [illegible]he second problem is more oriented toward assessing the cost and production impact of short-term budget adjustments.

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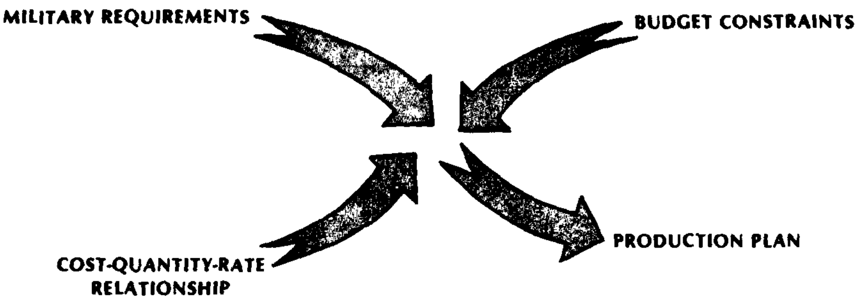
FIGURE 1
Factors Leading to Development of a Production Plan



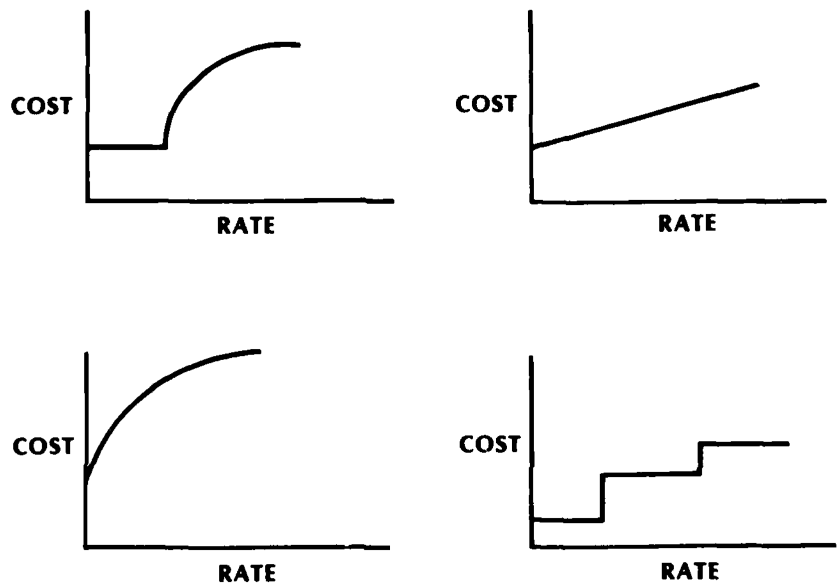
Several research studies have considered the effect of rate on weapon-system cost. An extensive review of these studies was conducted as an initial step in a recent study conducted by the U.S. Army Procurement Research Office.[1] Only a few key studies and their findings will be mentioned here.

A 1974 RAND study attempted to modify the usual learning-curve approach by testing models across airframe programs with an additional rate term.[2] These researchers were forced to conclude that a general cost-rate relationship could not be predicted with any degree of confidence. For advanced planning purposes they recommended ignoring rate effects in aircraft production programs because they were dominated by other uncertainties. Note that the researchers did not claim that rate does not have an important effect, only that the rate effect was not predictable with the models tested. Although confined to airframes, this work suggests that it is unrealistic to expect to obtain a single general rate-cost model, even within a product class.

Some Air Force researchers have had modest success with a different approach.[3] Rather than attempt to determine a general model, these researchers fit a regression equation with a production rate term to the historical data for a single program. They typically obtained reasonably good fits and a statistically significant rate term. Although they applied the model to direct labor costs, the technique could be used for total production costs and applied in any product area.

1. C. H. Smith, *Production Rate and Weapon System Cost: Research Review, Case Studies, and Planning Model*, APRO 80-05. Fort Lee, Va.: U.S. Army Procurement Research Office, 1980.
2. J. P. Large, *et al.*, *Production Rate and Production Cost*, R-1609-PA&E, Santa Monica, Calif.: RAND Corporation, 1974.
3. See, for example, the following: L. L. Smith, *An Investigation of Changes in Direct Labor Requirements Resulting from Changes in Airframe Production Rate*, Unpublished Ph.D. Dissertation, University of Oregon, 1976.

FIGURE 2
A Few Possible Behaviors for Overhead Cost Elements



The principal drawback to this approach is the extensive data base required on a specific program before the model can be used. Most key decisions are made before such a data base can exist. The model has no generality because wide variations in parameter values have occurred for systems with similar production quantities and rates.

The general conclusions that can be drawn from the existing empirical research base are limited. It is clear that rate affects unit costs and that the specific effect is highly dependent on program specific features. Typically, unit cost estimates are much less sensitive to rate uncertainty than to total program quantity uncertainty. Finally, for the planning problem there is evidence that the overhead cost element frequently accounts for a much greater proportion of the rate effect than do inefficiencies in the use of material or labor. A few possible behaviors of overhead cost elements as a function of rate are shown in Figure 2.

The conduct of empirical research in this area is fraught with difficulties. In dealing with historical rate data it may be impossible to know the rate for which the facility was designed. It also may not be possible to know the amount of time available to the contractor for planning and adapting to a rate change. Likewise,

the optimal, as distinct from the planned, rate may not be known. Some approaches to data gathering invite bias. This is especially true of techniques using contractor-supplied data to which the contractor has not been contractually committed. Thus, contractor historic data is preferred because it is an objective measure of what actually happened. In the cost-rate area one also risks searching for fine differences concealed by larger system disturbances.

In our own research, several missile systems were investigated to gain additional insight into the effects of production rate on system cost. The six missile systems examined covered a broad spectrum of conditions. Included were cases with very long production histories, and cases only now in production planning for low-rate initial production. The cases also varied from low-volume, labor-intensive production such as Pershing to high volume, highly automated production such as that planned for the multiple launch rocket system (MLRS). One case had steady rates during production periods but was plagued with breaks in production. Other cases had U.S. Army rate effects highly buffered by foreign military sales. One system was experiencing an extended period of low-rate production because an improved version of the system was on the way. Such a variety of circumstances found within even a single product class makes generalization difficult.

Nevertheless, these investigations led us to recommend certain actions. For example, in agreement with earlier work, it was suggested that low-range planners focus on military requirements without regard to rate behavior. At that stage, rates and their effects are unpredictable and dominated in importance by more fundamental choices. As appropriate, the government should require contractors to explain as part of their proposals the mechanisms for accommodating rate changes. This action should encourage manufacturing flexibility in adapting to rate changes. Since the size and structure of the defense industry are ultimately major factors in production costs, further study should be conducted of the optimal structure of the defense industry and its relationship to the defense budget. Finally, a simple model based on overhead considerations should be used for programming and budgeting estimates under rate changes.

Several theoretical cost-rate models have been proposed. While the models differ in several respects, most either address the wrong problem or require the estimation of too many difficult, detailed parameters for top-level planners. None has seemed suitable for use as a general tool for budget planners. One proposed estimation model is suggested below. It seems to provide a degree of insight for many cases with limited data requirements. The model is based on the premise that costs dependent on time rather than cumulative quantity are the major explainers of the cost impact of rate changes.

To illustrate the approach, consider program planning for a system prior to the beginning of actual production. Suppose that a total quantity of Q units of the system will be bought. What is the estimated cost per unit if the system is procured uniformly over T years?

Let the variable costs y for the x^{th} unit be given by $y = ax^{-b}$ where a, $b>0$. If the acquisition period is T years, then the annual production rate is Q/T. Let the annual fixed costs allocable to the progam be constant and denoted by F. Then the average unit production cost A for all production is given by

$$\frac{\sum_{k=1}^{Q} a\, k^{-b} + T\cdot F}{Q} \approx \frac{\left(\frac{a}{1-b}\right) Q^{1-b} + T\cdot F}{Q}$$

This model is useful for estimating the average unit cost differences for procuring the same total quantity under different rates. It is easy to modify the model to accommodate fixed costs that change from year to year, provided these can be estimated. Likewise, a slight modification is required to deal with those cases where substantial production experience is acquired for units not sold to the analyzing buyer, e.g., foreign military sales. Discount factors can also be incorporated as needed.

The following example illustrates the use of the model and the predicted effect on costs.

Example. Two production plans under consideration are given in Table I. Both options result in an overall production volume of 120,000 units. Let the variable costs $V(k)$ for both plans be expressed by the following

Variable cost for k^{th} unit $= V(k) = 10{,}000k^{-.152}$.

This expression assumes a 90 percent learning curve and describes variable cost reductions as a function of the cumulative quantity produced. Also, let the annual fixed costs of maintaining the program be \$10 million.

TABLE I
Alternative Production Plans; Annual Production (in 1000 s)

Year	Option 1	Option 2
1	20	40
2	20	40
3	20	40
4	20	—
5	20	—
6	20	—

Applying the model, the average cost per unit under Option 1 is

$$\frac{\left(\sum_{k=1}^{120,000} 10000k^{-.152}\right) + 6(10^7)}{120,000} \approx \$6993.$$

Under Option 2 the estimated average cost per unit is

$$\frac{\left(\sum_{k=1}^{120,000} 10000k^{-.152}\right) + 3(10^7)}{120,000} \approx \$4493.$$

In this hypothetical example the estimated average unit cost decrease is $2,500 when production follows Option 2 instead of Option 1. Thus, in this example, doubling the production rate for the entire program should save 36 percent of program production costs. Of course, in real life, decision-making factors such as changes in military value dependent on time of production must be considered.

In the above example the model was used to project the cost effect of rate options on a program in the production planning stage. Frequently, however, the principal concern is to estimate the cost effect of a rate change for next year on a current production effort. A variation in the above model handles this problem.

The real test of the usefulness of the model is the accuracy of its predictions. One indicator of that accuracy is described below. Only one study was found that analyzed rate effects in sufficient detail to permit comparison. A detailed examination was made of the effects of rate changes on MLRS costs.[4] The researchers analyzed in detail the capital equipment changes and other items required by rate adjustments. This study was only a forecast of cost effects because no production had taken place. The study finding must not be taken as current projections of MLRS behavior because the contractor analyzed was not the winner of the competitive selection process. Nevertheless, the approach taken was very detailed and radically different from the simple model proposed here. It stands as one test of the predictive ability of the model. The accuracy of the model in matching the detailed study findings is a matter of judgment. Moreover, one detailed comparison does not suffice for arriving at conclusions. More such case

4. *Analysis of the Effects of Production Rate and Quantity Changes on Production Costs*, Science Applications, Inc. (Prepared for MLRS Project Office under Contract No. DAAK40-79-D-00006), Huntsville, Ala., 1980.

analyses are required to increase confidence in such models. In this case, however, the model seemed to anticipate the effect of rate changes.

It is obvious that the fixed-cost-based model is not totally accurate. It appears, however, that use of such a model would refine current macro-level budget practices. The model should not be strained too hard by employing it carelessly over too great a range of rates. The accuracy of these simple tools probably falls rapidly after much more than a 50 percent rate increase or 100 percent rate decrease. In the short-term analysis one must recognize a greater amount of fixed costs. One reason is the unwillingness of a firm to cut back labor in proportion to the short-term rate cut.

Finally, any of these cost models provides information along only one dimension of the overall problem. Changing rate means, in a sense, procuring a different system, for the military value of a system is a function of its availability. Simple arguments based on willingness to incur total system costs could often suggest that stretch-out is much more costly in terms of estimated military value than in terms of production costs. Too much relative emphasis is typically placed on the cost side of the cost-value spectrum, simply because it is more easily quantified.

The suggestions below are unproven, but they represent reasonable decision rules today. Decisions are grouped here into the three classes of advanced planning, budgeting, and negotiations. It is proposed that rate effects be ignored for advanced planning purposes. In the budgeting phase one can use a rough rule of thumb that suggests a per-unit price rise of 0–10 percent for a downward rate adjustment of 50 percent. The exact percentage used should be biased toward one extreme or the other based on system specific information. If sufficiently reasonable estimates are available, the model suggested above could be applied at this stage. More data may be available in the contract negotiation stage. If sufficient production history exists for the system, applying a program specific regression technique is recommended.

A fuller understanding of the contingent nature of the rate problem is a massive undertaking whose value depends on the cost-rate effects on decision-making. Readers are invited to contribute to the advancement of this research area through added empirical knowledge of additional commodities and through conceptual advances.

Three Views of the Impact of Production Rate Changes—III

A Model for Examining the Cost Implications of Production Rate

84

John C. Bemis

The issue of production rates for defense systems has recently been given increased emphasis as an important element of systems affordability. This emphasis is evident within the Department of Defense, in the Congress,[1] and in the General Accounting Office.[2]

Investigation into the relationship between production rate and production cost for defense systems indicates significant variations in cost as a function of production rate. A model that relates production rate, unit cost, and cumulative quantity has been developed. It provides planning information of sufficient accuracy to assist in the selection of economical production rates, and can be applied to a wide range of complex systems.

Department of Defense Instruction 5000.2, "Major System Acquisition Procedures," requires that production rate/cost relationships be addressed at program Milestone II (full-scale development) and at Milestone III (production and deployment). This requirement establishes the need for a method to explore these relationships.

A review of the June 30, 1980, selected acquisition reports[3] for the 46 current major weapon systems indicated that a $19.1 billion cost growth has resulted from schedule changes on these programs, which proves that production rates have a significant influence on the cost of defense systems. Data compiled by the General Accounting Office show that the production rates for fighter aircraft have declined from 600-700 per year in the 1950s to less than 150 per year in the 1980s.

In this article, I propose one method for estimating rate/cost/quantity relationships using cost estimates or empirical data points which are unique to each system. Methodology for performing the analysis is explained, and an example is given. Arithmetic operations were performed using a time-sharing computer with its available routines for regression analysis. The current generation of hand-held

1. U.S. House of Representatives, *Department of Defense Appropriation Authorization Act 1979*, Report No. 95-1573.

2. U.S. General Accounting Office, *Impediments to Reducing the Costs of Weapon Systems*, Report PSAD-80-6, November 1979.

3. Winfield S. Scott and Gregory E. Maust, *A Comparison of Cost Growth in Major Missile Systems with That Experienced in Other Major Weapon Systems*, Washington, D.C.: Office of the Secretary of Defense (Comptroller), October 1980.

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calculators is also capable of making the calculations. In this article, unit cost is defined as cost to the customer.

Rate/Cost/Quantity Model

Traditionally, system unit costs have been projected using the familiar experience curve. This method depicts the projected unit cost as a function of cumulative quantity produced, without regard for the production rates involved. Variations in unit cost as a function of production rate appear to be largely due to amortization of fixed overhead. The rate/cost/quantity model discussed here adds production rate as the "Z" axis of a three-dimensional response surface. This model is based on the model developed as a result of investigations into the relationship between direct labor requirements and production rate by L. L. Smith[4] and further verified by others.[5]

Data inputs for this model consist of historical rate/cost/quantity data for ongoing programs, and contractor or in-house estimates for new programs. Only unit-fly-away (roll-away, swim-away, etc.) costs are considered, not total program costs. A multiple regression is performed in which unit cost is the dependent variable, and cumulative quantity and production rate are the independent variables. By this method, an equation is derived which describes the three-dimensional response surface relating these variables. Most of the sets of data analyzed in this manner to date show a high multiple correlation coefficient (in excess of 0.9). Figure 1 depicts this response surface and the relationship between the variables.

Figure 2 depicts the response surface for a hypothetical weapon system and will serve to compare the experience curve method with the rate/cost/quantity method.

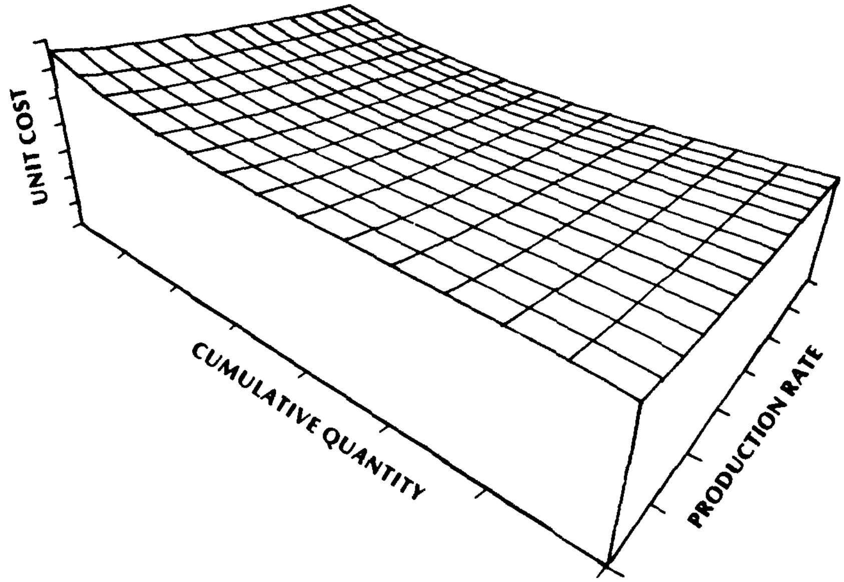
Given:

—First unit cost = $1000 for a rate of 600 units/year
—90 percent experience curve slope (exponent - .152)
—85 percent rate cost curve slope (exponent - .235)
—6000 units to be produced

4. Larry Lacross Smith, *An Investigation of Changes in Direct Labor Requirements Resulting from Changes in Airframe Production Rate.* Eugene, Oregon: University of Oregon, June 1976. Ph.D. Dissertation.

5. Duane E. Congleton and David W. Kinton, *An Empirical Study of the Impact of a Production Rate Change on the Direct Labor Requirements for An Airframe Manufacturing Program.* Wright-Patterson Air Force Base, Ohio: Air Force Institute of Technology, September 1977.

FIGURE 1
Response Surface Relating Unit Cost, Cumulative Quantity, and Production Rate



Experience curve method:

$$(1) \quad \underline{Y = AX^{B} = 1000\ X^{-.152}}$$

Rate/cost/quantity method:

$$Y = (K)\ \text{Quantity}^{-.XXX}\ \text{Rate}^{-.YYY}$$

Using first unit cost data point to solve for K:

$$1000 = (K)\ 1^{-.152}\ 600^{-.235}$$

$$K = 4482$$

Therefore:

$$(2) \quad \underline{Y = 4482\ Q^{-.152}\ R^{-.235}}$$

When equations (1) and (2) are used to project unit costs vs. cumulative quantity at a constant production rate of 600 per year, the results are identical. When they are used to predict unit costs for a variable *production rate,* the results are shown in

FIGURE 2
Comparison of Experience Curve with Rate/Cost/Quantity Method

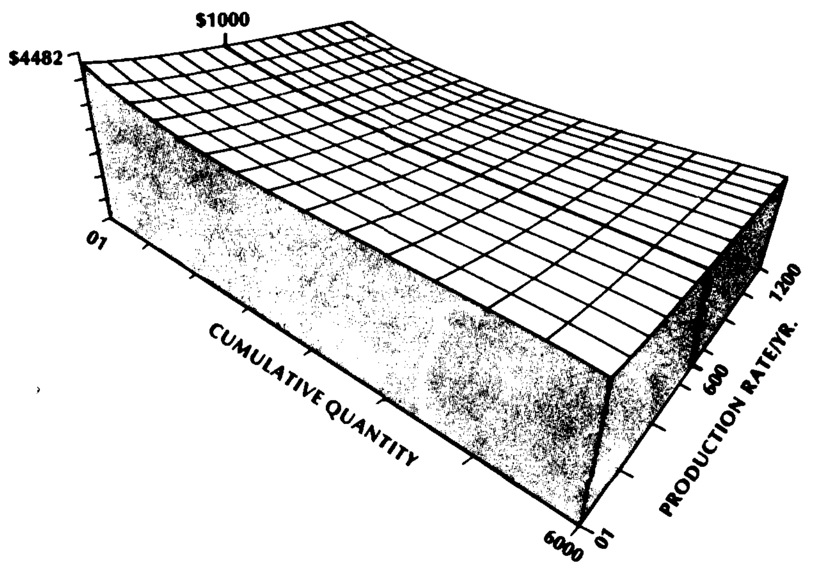


Figure 3. As can be seen from this figure, the lower unit costs are associated with the higher production rates, and the higher unit costs are associated with the lower production rates

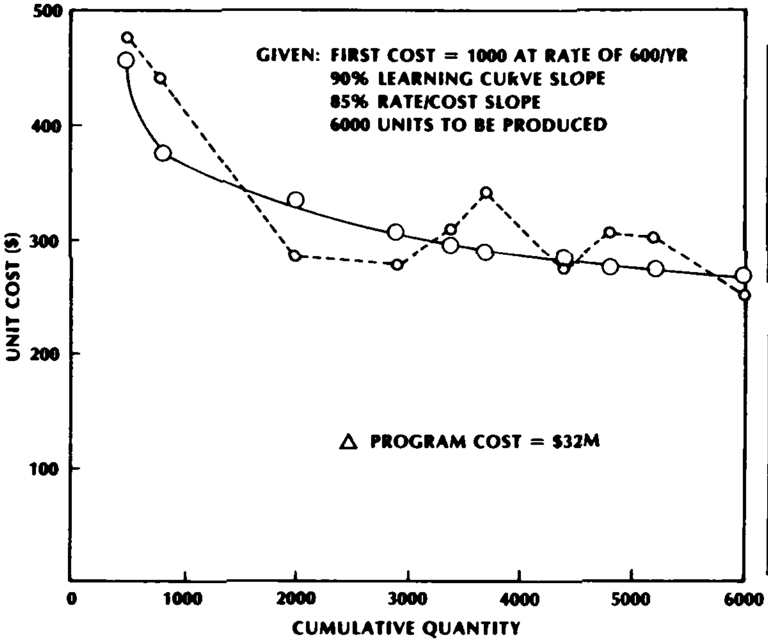
Case Study

The following example of rate/cost/quantity relationships is based on data from an actual weapon system. The data have been masked by changing the first unit cost and by using a different region of the response surface in terms of production rates and quantities produced. The exponents for quantity and rate, as well as all the correlation coefficients are the actual values resulting from the analysis. Input data for the analysis consisted of:

—Annual quantities produced (rate)
—Average unit cost by year
—Cumulative lot mid-points for each year

After these data were entered into the computer, the following calculations were performed:

FIGURE 3
Comparison of Predicted Unit Costs



○ RESULTS FOR Y = 1000 Q -.152

UNIT COST	YEARLY COST	QUANTITY	CUM QTY
457.5525	220776.2	500	500
374.1584	112247.6	300	800
334.3567	401228.3	1200	2000
305.6545	275089.2	900	2900
293.9675	146983.8	500	3400
288.6455	86593.69	300	3700
282.9568	198069.8	700	4400
277.4951	110998.1	400	4800
273.9985	109599.5	400	5200
269.3386	215471.1	800	6000
314.1758	1.885055E + 06	6000	

○ RESULTS FOR Y = 4482 Q -.152 R -.2345

UNIT COST	YEARLY COST	QUANTITY	CUM QTY
477.5334	238766.7	500	500
440.1917	132057.5	300	800
284.1904	341028.6	1200	2000
277.9260	250134.1	900	2900
306.8059	153403	500	3400
339.5062	101875.9	300	3700
272.9077	191035.4	700	4400
305.1716	122068.7	400	4800
301.3259	120530.4	400	5200
251.7643	201411.4	800	6000
308.7170	1.852308E + 06	6000	

—A log transform was made for each variable
—A linear multiple regression was performed in which unit cost was the dependent variable, and production rate and cumulative quantity were the independent variables.
—Independent regression analyses were performed for rate vs. cost and quantity vs. cost.
The results of these analyses were as follows:
—The equation for the response surface describing the relationship between unit cost, production rate, and cumulative quantity was determined to be:
-Unit cost ($\$K$) = 500 X Quantity$^{-0.1848}$ X Rate$^{-0.1135}$
—Multiple correlation coefficient (R) = 0.966
—Results of the individual regression analyses:
-Unit cost vs. quantity R = -0.908
-Unit cost vs. Production Rate R = -0.712
—Slope of the quantity/cost line (experience curve) = 88 percent
—Slope of the rate/cost line = 92.4 percent
These results were used to describe a rate/cost/quantity response surface similar to the one depicted in Figure 1.

When viewed from three separate viewpoints, some interesting relationships between unit cost, production rate, and cumulative quantity are revealed. Figure 4 depicts a view from the side of the response surface in which unit cost is the vertical axis, and cumulative quantity is the horizontal axis. From this vantage point, production rates of interest are displayed as a family of curves. In this example, production rates of 96, 180, and 300 units per year are shown. Figure 5 depicts a view from the end of the response surface in which unit cost is the vertical axis and production rate the horizontal axis. Cumulative production quantities of 300, 600, 900, and 1,200 are shown as a family of curves. When horizontal "slices" are made through the response surface, thus depicting constant unit costs, and the response surface is viewed from the top, the results are shown in Figure 6. In this view production rate is the vertical axis and cumulative quantity the horizontal axis. The iso-unit cost lines represent instantaneous values of unit cost and illustrate the wide variation in unit costs which may be experienced as a function of production rate and cumulative quantity produced.

Together, these views of the production rate, cumulative quantity, unit-cost response surface, are of considerable value in responding to the "what if" questions which arise during the planning and budgeting cycles for each system.

A cumulative cost response surface can also be constructed. This surface depicts total cost as the vertical axis and quantity produced as the horizontal axis. The family of curves in this case is production rate. Discussion of this analysis is beyond the scope of this paper.

FIGURE 4
Side View of the Rate/Cost/Quantity Response Surface

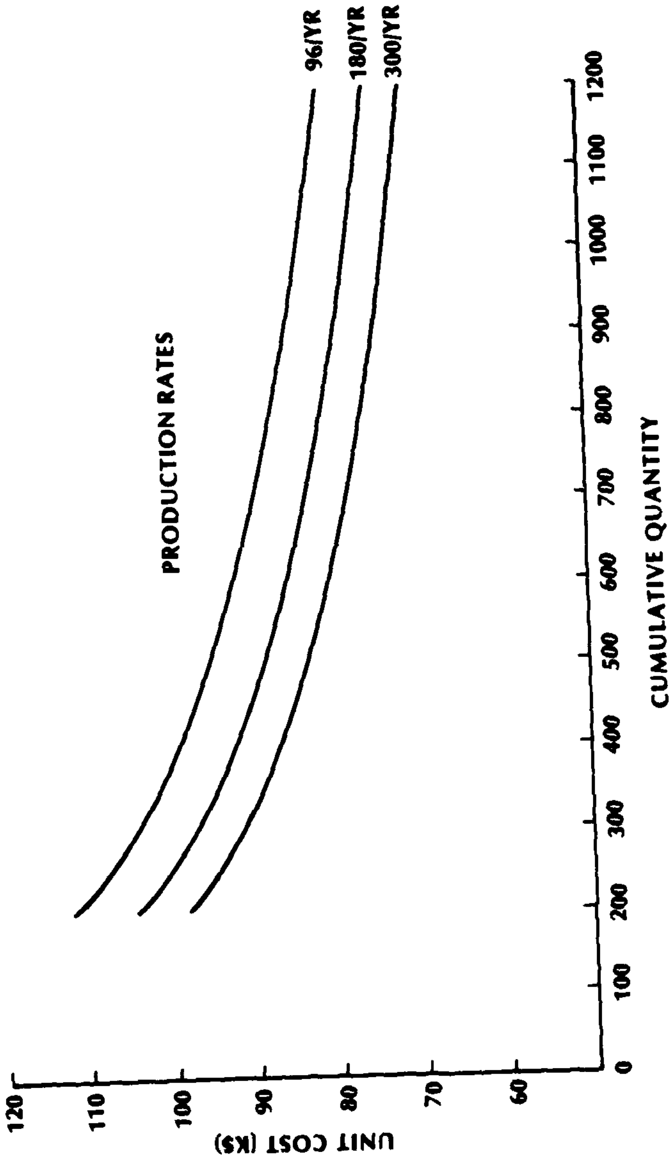


FIGURE 5
End View of the Rate/Cost/Quantity Response Surface

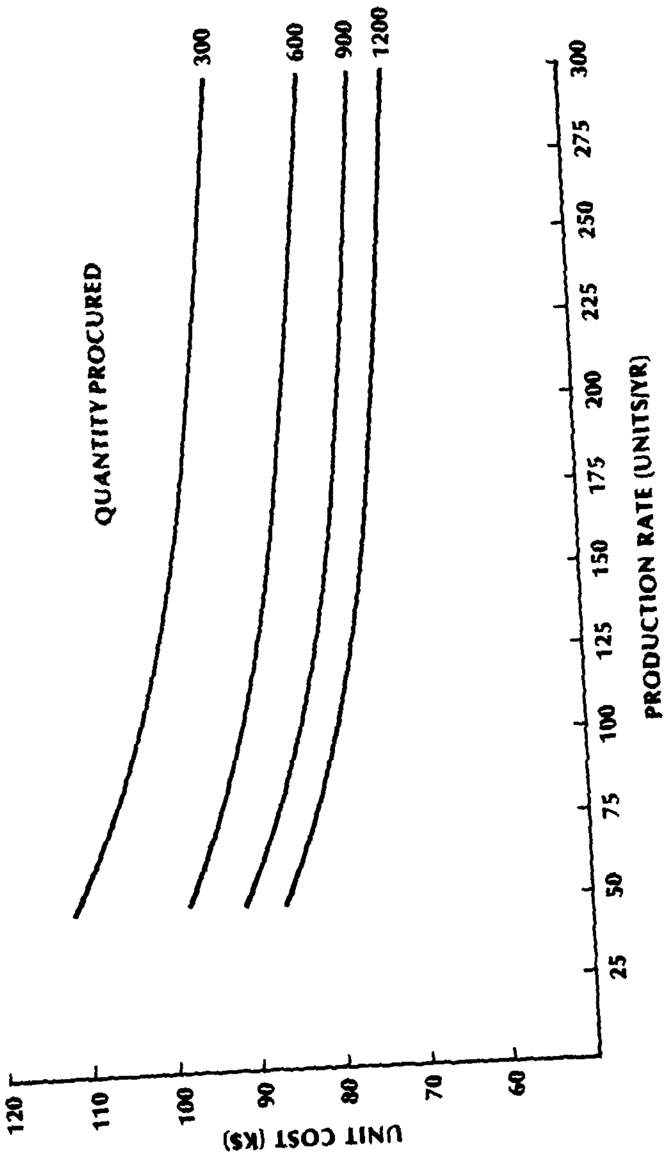
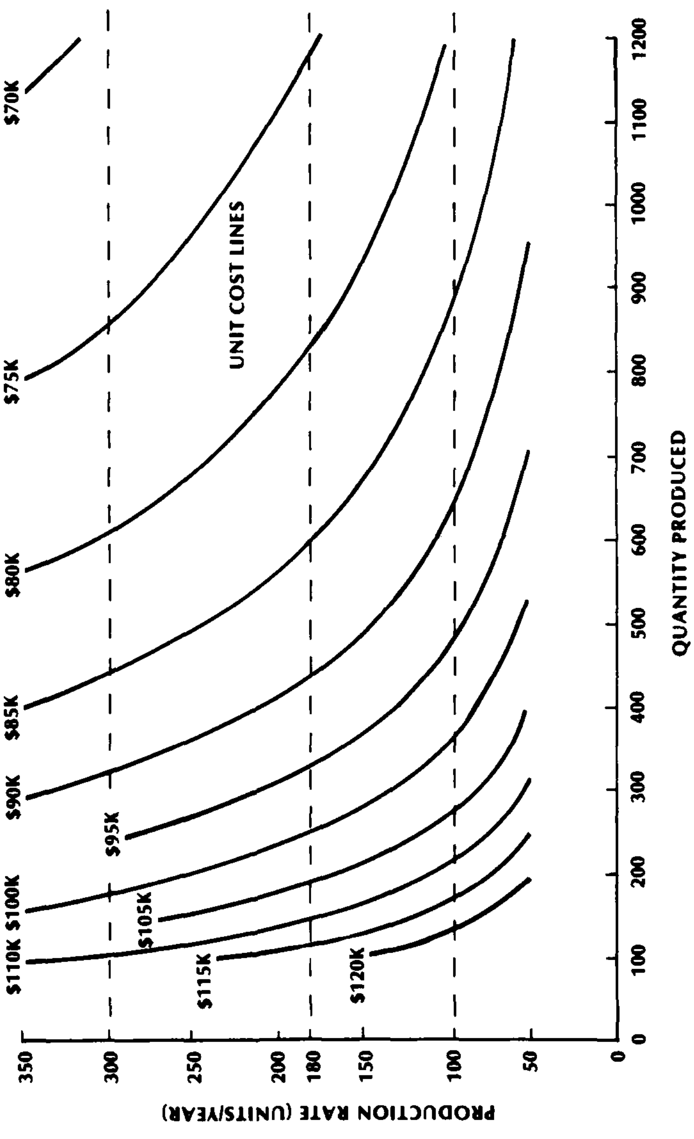


FIGURE 6
Top View of the Rate/Cost/Quantity Response Surface



Cautionary Notes

The use of the rate/cost quantity response surface is useful in displaying relationships between these variables; however, some words of caution should be expressed. When using this technique, the following should be kept in mind:

—Since the multiple correlation is made using transformed data, the resulting correlation coefficients apply to the transformed data rather than the original rate/cost/quantity data. Correlation coefficients for the original input data may be larger or smaller than those of the transformed data.

—For planning purposes it may be necessary to extrapolate values outside the range of the input data. This should be done with extreme caution, with due consideration being given to the other variables which may affect rate/cost/quantity relationships. Among these variables are the capacity of existing tooling and facilities, availability of manpower, ability of major subcontractors to supply the required sub-systems and materials, and the effects on other concurrent programs.

—Since production rate and cumulative quantity are not truly independent variables, in some cases a high degree of multicolinearity may exist. This may result in a change in sign for one of the variables in the equation for the response surface. This can be corrected by the use of "dummy" data points derived from actual data and the results of the individual regression analyses. This remedy, however, adds uncertainty to the overall results.

—Results from the analysis of several systems indicate that a wide variability exists in the slopes of the quantity/cost lines and the rate/cost lines. Use of industry average or commodity average slopes may introduce substantial error into rate/cost/quantity projections.

Summary

Although production rate is just one of the important variables to be considered in the acquisition of defense systems, it is important in terms of unit cost. Other important variables, of course, would be military requirements, contractor tooling capacity, ability of subcontractors to supply components, operation and support considerations, etc.

The model presented in this paper uses constant dollars throughout. In addition to the difference in program cost in terms of constant dollars, additional costs are incurred through a longer exposure to inflation. Of the $19.1 billion for schedule changes on the current SAR programs, approximately one-third are constant dollars and two-thirds are due to inflation. It is difficult to annualize these figures because some of the systems have been on line for a number of years, and others are just going into production. In addition to the fact that production rate vs. production cost considerations are required to be made at DSARC II and III,

use of the rate/cost/quantity model can be invaluable in e loring the inevitable "what if" questions that arise during the planning and budgeting cycles. Graphic displays of the rate/cost/quantity relationships allow rapid approximations of the effects of incremental funding changes on the specific program as well as the effects of changes in quantity procured. Other questions that can be approximated from the graphic displays are the cost effects of program stretchouts, costs of maintaining a warm production base, and the probable effects of program acceleration. ||

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The VAMOSC Connection: Improving Operating and Support Costing

Alvin M. Frager

The increasing complexity and unit cost of weapon systems have resulted in significant increases in acquisition costs. At the same time, these increasing complexities have resulted in less reliable systems that are more difficult to maintain.

Increases in operations, maintenance, and military personnel accounts have not been due solely to equipment maintenance problems. Recurring manpower shortages have compounded maintainability problems. When these are joined with the significant increases in energy costs, O&S costs increase drastically.

The priorities of defense systems acquisition managers are generally focused towards on-schedule development and deployment of weapons that meet specific capabilities. However, Jacques Gansler, in his book, *The Defense Industry*, restates the generally accepted notion that "the extreme R&D emphasis on equipment performance has rapidly increased the cost of military equipment and has thus greatly reduced the quantities of equipment procured. Performance has been increased, but at too high a cost."[1]

In the current environment of constrained budgets, defense buys fewer, more expensive weapons. Concurrently, force readiness suffers because of inadequate logistics support.

The recent presidential campaign addressed this problem and its impact on defense readiness in the debate that focused on the need for increased defense funding and better defense management. The recognition of support cost and readiness concerns has started to produce greater understanding of trade-offs necessary to control total cost.

Design-to-cost initiatives continue to focus management attention on program producibility. They motivate the services and industry to search for lower cost design alternatives to satisfy mission requirements. DOD Directive 5000.28, released in May 1975, stated that: "Design-To-Cost is a management concept wherein rigorous cost goals are established during development and the control of systems costs (acquisition, operating, and support) to these goals is achieved by practical tradeoffs between operational capability, performance, cost, and schedule. Cost, as a key design parameter, is addressed on a continuing basis and as an inherent part of the development and production process." This directive formalizes DOD's intention to manage defense system life-cycle costs (LCC).[2]

1. See J. S. Gansler, *The Defense Industry*, The MIT Press 1980.

2. The life-cycle cost of a system is the total cost to the government of acquisition and ownership of that system over its full life. It includes the cost of development, acquisition, operation, support, and where applicable, disposal. DODD 5000.28, May 1975.

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Clearly, DODD 5000.28 generates designer emphasis on life-cycle cost, but in doing so it recognizes that the key problem associated with LCC management and reduction is the ability to estimate the O&S cost of weapon systems: "Because of the ability to more accurately estimate production costs and the supportive production cost data base available, initial goals for Design-To-Cost shall be established in the form of Average Unit Flyaway (Rollaway, Sailaway) cost. Programs to strengthen the data base of weapon system operation and support (O&S) cost shall continue. As the ability to translate O&S cost elements into design requirements improves, Design-To-Cost goals may be extended into this area."

Consistent with this guidance, DOD defined a management by objective initiative 9-2, committing DOD to "define and establish a management information system which will provide data on maintenance and operation cost by weapon system." Each of the services responded to the MBO by efforts directed towards development of a prototype O&S cost information system. Within the acquisition process, VAMOSC reports are intended to provide explicit O&S cost-related data, consistent with Department of Defense O&S costing guidance outlined several times by the Office of the Secretary of Defense, Cost Analysis Improvement Group (CAIG).

The VAMOSC goal is to provide O&S cost reports for each major weapon type and series. At this time, Navy VAMOSC reports are available for 4 years for aircraft, and for 2 years for most ships. Air Force VAMOSC reports have been developed for all aircraft by an initial system, and the Air Force has a major revision currently underway that will be operational in several years. VAMOSC reports for other Air Force weapon systems are expected to follow. Army VAMOSC products are under design and development.

VAMOSC data are being developed in two basic costing formats. The first provides data for each weapon type in a "top level" cost element structure (CES). An abbreviated example of the Navy report for air systems is shown in Figure 1, and for ships in Figure 2. The cost data provided in these top-level VAMOSC reports reflect system demands and material consumption.

The second type of VAMOSC report provides maintenance-related cost data at a detailed level. Figure 3 is an illustration of this report for Navy aircraft. This report provides designers and analysts with information identifying hardware and logistics-related cost drivers. A report is available that identifies comparable costs for ship equipment. The detailed cost data in Figure 3 are summarized to each cost element and to the total system.

With these products, the system designer and cost analyst have the necessary data to improve the approaches to estimate O&S costs of alternatives at all hardware levels, and to provide a basis in experience to comment on the cost impact of proposed system changes. An evaluation of a proposed system that considers

FIGURE 1
NALCOMIS-O&S/VAMOSC-AIR

NALCOMIS-O&S/VAMOSC-AIR

NAVY AND MARINE CORPS AIRCRAFT COST REPORT BY T/M/S

VAMOSC-AIR TSS FY 1978 — ($ IN THOUSANDS DATA AS LISTED) — T/M/S A-7E — PAGE 2

	PACFLT	LANTFLT	NET	MARINE	RESERVE	NAVAIR	OPNAV	NAVEUR	MISC	TOTAL
INTERMEDIATE										
MILITARY PERSONNEL COST	0	.0	.0	0	0	0	0	0	0	0
CIVILIAN PERSONNEL COST	0	.0	.0	0	0	.0	0	0	0	0
CONTRACT PERSONNEL COST	.0	.0	0	0	0	0	0	0	0	0
** SUBTOTAL PERSONNEL	.0	.0	0	0	0	0	.0	0	0	0
MAINTENANCE SUPPLIES	6,421.8	4,805.1	0	0	0	95.3	0	.0	0	11,322
*** INTERMEDIATE SUBTOTAL	6,421.8	4,805.1	.0	0	0	95.3	0	0	0	11,322
	PACFLT	LANTFLT	NET	MARINE	RESERVE	NAVAIR	OPNAV	NAVEUR	MISC	TOTAL
DEPOT SUPPORT										
AIRCRAFT REWORK INTRA DOD	7,688.4	8,540.1	0	0	0	110.6	.0	0	0	16,539
AIRCRAFT REWORK COMMERCIAL	303.7	328.8	0	0	0	4.2	0	0	.0	636
** SUBTOTAL A/C REWORK	8,192.2	8,868.9	0	0	0	114.9	0	0	0	17,176
ENGINE REWORK INTRA-DOD	12,419.2	13,445.2	0	0	0	184.4	0	0	0	26,048
ENGINE REWORK COMMERCIAL	.0	.0	0	.0	0	.0	0	0	0	0
** SUBTOTAL ENG REWORK	12,419.2	13,445.2	.0	0	0	184.4	.0	0	0	26,048

PAGE 1-2

FIGURE 2
VAMOSC-SHIPS

VAMOSC-SHIPS
OPERATING AND SUPPORT COSTS TOTAL BY SHIP
FY-1977

PAGE 01

	UIC	02533	C2534	02535	02536	02537	02538	03128	03129	03130
	NAME	BOLSTER	CNSERVR	HOIST	OPORTUN	RCLAMER	RECOVRY	THOMSTN	PLYMOUT	FT SNEL
	SHIP TYPE	ARS	ARS	ARS	ARS	ARS	ARS	LSD	LSD	LSD
	SHIP HULL NO	0038	0039	0040	0041	0042	0043	0028	0029	0030
	NUMBER OFFICER PERSONNEL-NAVY	8	7	7	6	6	7	20	20	19
	NUMBER ENLISTED PERSONNEL-NAVY	74	79	79	78	78	78	323	312	317
	NUMBER OFFICER PERSONNEL-MARINE	0	0	0	0	0	0	0	0	0
	NUMBER ENLISTED PERSONNEL-MARINE	0	0	0	0	0	0	0	0	0
ELEMENT NUMBER	ELEMENT DESCRIPTION	($ IN THOUSANDS)								
1.0	DIRECT COSTS	1146	1167	1122	1076	1177	1371	4180	4246	5228
1.1	• PERSONNEL	861	886	866	871	879	901	3344	3167	3224
1.1.1	MANPOWER	859	885	865	870	878	901	3338	3160	3212
1.1.1.1	REPORTED MAINTENANCE LABOR	14	12	40	8	23	7	62	6	75
1.1.1.2	OTHER MANPOWER	845	872	824	862	855	894	3276	3154	3137
1.1.2	TAD	2	1	1	0	1	1	6	8	12
1.2	• MATERIAL	249	243	223	188	242	225	666	1008	1926
1.2.1	SHIP POL	111	63	102	87	128	95	228	607	1252
1.2.1.1	FUEL (FOSSIL)	104	59	101	77	125	94	226	597	1245
1.2.1.1.1	UNDERWAY	76	0	99	57	110	77	199	3[illegible]5	0
1.2.1.1.2	NOT UNDERWAY	28	0	2	20	15	17	27	293	0
1.2.1.2	OTHER POL	7	4	1	11	3	0	2	9	7
1.2.2	REPAIR PARTS	76	31	54	35	53	54	151	174	434
1.2.2.1	REPORTED REPAIR PARTS	4	2	13	2	2	5	10	5	69
1.2.2.2	OTHER REPAIR PARTS	14	5	16	7	3	27	31	73	156

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FIGURE 3
Sample MS Report

AIRCRAFT = A-4M TYPE EQUIPMENT = AACP OCT. 78 - SEPT. 79
TOTAL COMPONENT MAINTENANCE COSTS(IN THOUSANDS OF $)

ORG.LEVEL LABOR RATE = 15.56 PER HOUR
INT.LEVEL LABOR RATE = 15.56 PER HOUR

ALL-NAVY SQUADRONS

WORK UNIT CODE	ORGANIZATION MAINTENANCE LABOR SCH	ORGANIZATION MAINTENANCE LABOR UNSCH	ORGANIZATION MAINTENANCE CONSUM SCH	ORGANIZATION MAINTENANCE CONSUM UNSCH	ORGANIZATION SUPPT LABOR	ORGANIZATION IDC LABOR	INTERMEDIATE MAINTENANCE LABOR SCH	INTERMEDIATE MAINTENANCE LABOR UNSCH	INTERMEDIATE MAINTENANCE CONSUP SCH	INTERMEDIATE MAINTENANCE CONSUP UNSCH	INTERMEDIATE SUPPT LABOR	INTERMEDIATE IDC LABOR	INTERMEDIATE ATTR	DEPOT COMPONENT REPAIR NARF D-LAB	DEPOT COMPONENT REPAIR NARF I-LAB	DEPOT COMPONENT REPAIR NARF MAT	DEPOT COMPONENT REPAIR COMMERC LABOR	DEPOT COMPONENT REPAIR COMMERC MAT	DEPOT SURV	DEPOT IDC LABOR	WUC TOTAL COST
03	1143	0	0	0	719	0	106	0	0	0	21	0	0	0	0	0	0	0	0	0	1989
11	30	167	21	110	93	12	1	12	0	3	9	0	21	10	17	27	0	0	83	0	611
12	2	16	1	7	6	2	0	0	0	0	0	0	0	2	2	3	0	0	1	0	45
13	17	249	7	70	78	1	5	130	0	4	29	0	60	16	27	20	43	9	14	0	778
14	12	169	5	56	77	3	1	13	0	2	9	0	19	37	59	32	0	0	36	0	530
23	25	146	2	21	20	7	82	70	75	11	124	11	0	99	132	263	0	0	63	0	1141
24	11	135	5	53	49	11	3	61	0	1	26	0	48	20	30	55	552	109	77	0	1198
41	1	25	3	10	6	0	1	3	0	0	2	0	0	12	17	13	0	0	10	0	122
42	12	286	2	34	91	6	1	19	0	1	1	0	269	0	0	0	378	75	20	0	1198
44	3	68	3	75	22	0	2	54	0	0	2	0	0	0	0	1	91	18	0	0	340
45	2	29	2	13	13	0	1	1	0	0	1	0	0	4	6	9	0	0	4	0	85
46	17	97	1	20	34	4	0	12	0	0	4	6	4	15	22	19	0	0	21	0	275
47	0	7	1	7	4	0	0	22	0	1	1	0	3	1	2	1	14	3	0	0	70
49	1	23	1	19	4	1	0	0	0	0	0	0	0	4	5	1	0	0	1	0	69
51	4	116	4	36	19	1	1	19	0	0	3	0	4	60	80	27	0	0	20	3	394
55	1	60	0	4	9	1	1	108	0	3	2	0	0	10	14	10	133	26	16	0	400
57	0	47	0	1	5	0	1	19	0	0	1	0	0	8	11	8	0	0	16	0	118
59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	1	30	0	3	11	0	1	28	0	0	0	0	0	0	0	0	13	1	0	0	89
63	1	69	0	5	26	0	0	38	0	0	2	0	3	6	7	7	15	3	1	1	192
64	0	2	0	0	1	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	7
65	1	39	0	52	14	3	1	56	0	0	2	0	0	19	23	5	6	1	15	0	236
66	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
67	0	9	0	0	3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	15
71	1	25	0	5	8	1	0	13	0	0	1	0	2	8	11	16	0	0	6	2	99
72	1	31	1	15	10	0	1	27	0	0	1	0	19	7	10	2	82	13	2	14	238
73	5	222	1	31	41	4	3	171	0	2	4	0	30	52	69	24	405	80	0	0	1143
74	3	40	2	36	64	0	1	21	0	0	1	0	2	2	3	1	14	1	0	0	200
75	20	90	14	106	342	2	4	24	1	4	10	6	37	53	95	38	0	0	50	0	807
76	4	47	4	57	20	2	3	102	0	0	14	0	0	13	19	11	136	15	0	15	464
77	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
91	1	6	0	4	4	3	1	3	0	0	7	13	4	1	2	1	2	0	0	0	54
92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
93	0	6	0	3	3	0	0	1	0	0	1	0	6	0	0	0	0	0	14	0	34
96	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
97	1	10	0	0	3	6	0	0	0	0	1	0	0	0	0	0	0	0	0	0	23
TOTAL	1325	2270	83	873	1799	71	220	1037	77	33	279	36	520	449	666	595	1883	354	427	34	13041

PRE-EX MAT	74
UNALLOC ORG SUPPT LAB	1228
ORG IDC MAT	0
INT IDC MAT	0
DEP IDC MAT	0
GRAND TOTAL FOR A-4M	14343

IV - 1

design and logistic support differences between alternatives can be the basis of predictions of O&S cost differences. The differences in operating scenarios can be equated into O&S cost increments. When calculated costs are related back to the O&S cost reported by VAMOSC, the estimates for the new system can be directly compared to O&S cost-experience data for existing systems. An engineering-based costing technique such as this provides estimates that are credible, and therefore can be expected to be more acceptable to the decision-maker. Clearly, the approach taken by the user of VAMOSC data will be a critical element affecting the credibility of the estimates. With the detail and visibility provided by VAMOSC reports, the analyst can use existing costing methodology to develop improved O&S estimates.

The importance of cost management in new systems acquisition has already been reiterated in the new administration. In a memorandum distributed within DOD, the Deputy Secretary of Defense stated the priority objective to "reduce costs by looking for substantial and real savings in the acquisition of major weapons systems; . . .[3]

It is important that the systems design community increase their use of VAMOSC information. The designer must be able to recognize the impact on cost resulting from parameters that he can directly control. The designer may make a choice between a hydraulic or electric actuator. The program manager must choose between various material mixes. The Defense Systems Acquisition Review Council reviewers must understand the O&S cost impact of a degradation in system performance parameters. The cost variable in a decision needs to be described in terms that can be equated into specific design alternatives. In a gross sense, empty weight or engine thrust are parameters that a designer wants to control. These, however, are difficult for a designer to deal with in the specific trade-off studies where the design alternatives affect reliability of a component, its repair time, cost, material mix, alternative engine combustion cycles, location of access doors, and avionics level of modularity. The O&S cost factors must be explicitly related to design and support characteristics of hardware.

The most explicit approach for estimating an O&S cost factor commonly is referred to as "bottoms-up," or as an engineering build-up approach, illustrated in Figure 4. The estimate is "built up" by aggregating the contributions to the total cost made by significant system functional hardware items. In this case, the impact of each design-related input factor such as replenishment spares, component rework, etc., is built up by aggregating all of the contributions by hardware it [illegible] to that cost factor.

3. See Memorandum for Secretaries from the Deputy Secretary of Defense to major DOD offices, "Improving The Defense Acquisition System and Reducing System Costs," 2 March 1981.

FIGURE 4
F/A-XX Cost Factor Buildup

Bottoms-Up Costing Technique FY-80 $/FH				
WUC	SUBSYSTEM	REP. SP.	OOC	COMP RWK
11	Air Frame	10.05	14.16	9.53
12	Fuselage	.17	2.24	1.24
13	Landing Gear	11.30	21.01	22.79
14	Flight Control	11.54	8.37	16.61
24	APP	.11	.15	.41
27	Turbofan Eng.	17.12	3.46	36.56
29	Power Plant & Inst.	2.07	6.33	16.23
41	AC/Press/ICC Control	10.49	14.11	35.61
42	Electrical Power	.71	4.77	5.90
44	Lighting	—	4.21	1.85
45	Hydraulic & Pneumatic	.34	4.73	3.01
46	Fuel	1.48	7.59	10.15
47	Oxygen	1.23	.38	1.48
49	Misc. Utilities	3.07	8.81	6.51
51	Instruments	1.30	.87	4.77
56	Flight Ref.	7.22	50	2.75
57	Int. Guidance/Flight Control	7.47	3.60	1.84
58	In-flight Test	—	—	—
63	UHF	—	.50	7.06
64	Interphone	.84	.42	—
65	IFF	01	1.14	1.04
66	Emergency Radio	.01	.10	.01
67	COM-NAV-IFF	—	2.00	65.25
69	Misc. Comm.	—	—	—
71	Radio Nav.	—	.06	2.09
72	Radar Nav.	.05	.37	3.77
73	Bomb Nav.	4.86	6.06	25.23
74	Weapons Control	5.59	16.35	61.05
75	Weapons Delivery	2.84	1.71	7.15
76	Electronic Countermeasure	.76	2.25	5.46
77	Photo-Recon	—	—	—
91	Emergency Equip.	.03	.47	.49
92	Tow Target	—	—	—
93	Drag Chute	—	—	—
96	Personnel Equip.	—	—	—
97	Explosive Device	—	.01	.01
	TOTAL	100.66	136.73	355.85
		—	+ 25.50[1]	—
		$100.66	$162.23	$355.85

1 Contains pre-expended materials and personnel support supplies

The VAMOSC maintenance-related cost data can provide the needed detail for an analyst to build up the O&S cost estimate explicitly from design and logistics-related information. It can provide current experience data for existing, installed components that comprise the system. Typically, hardware in a weapon system evolves towards improved performance, and the general functions of the hardware will evolve from one system to its follow-on system. As such, it is to be expected that there is correlation of cost experience between current and advanced generation equipment.

With VAMOSC, cost-data analogies can be identified, or scaling techniques can be employed, to consider the impact of current operating hardware experience to advanced hardware operating in an equivalent environment. Where the system or function is unchanged, and the operating environment is equivalent, the existing VAMOSC data for the system or component may be assumed to be analogous to the anticipated experience for new system or component. In cases where equipment technology has advanced to the point where existing experience data cannot be considered directly analogous, the analyst is still better off with VAMOSC data because the estimate's uncertainty, due to lack of experience data, is limited to that specific hardware element of the total estimate. A bottoms-up estimate of key O&S cost factors, using a scaling approach, is illustrated in Figure 5. In this example, reliability and material cost factors have been developed that relate analogous equipment to new design equipment. Based on these scalars, an estimate has been developed for an advanced aircraft that can be compared to VAMOSC experience data for existing operational (e.g., benchmark) aircraft.

The bottoms-up costing approaches can be improved with the use of contractor logistic support analyses (LSA), or by data developed in comparability analyses that identify analogies or "like or similar" functions to existing hardware. During full scale development, cost estimates by hardware contractors for design trade-off analyses are more likely to use LSA data because such efforts are increasingly required as an integral part of the contractor design and integrated logistics support (ILS) planning process.

Specific approaches to O&S cost-factor estimation to the exclusion of others should be avoided because no single approach can be expected to credibly estimate costs in all situations. At any stage of a program's acquisition and design process, the specific hardware elements may be at different stages of definition and production, as well as being a mix of off-the-shelf and new-design hardware. The availability of VAMOSC data by weapon-system type and series allows an analyst greater flexibility to define and implement an estimating approach that will provide a more explicit O&S cost estimate. The cost estimate will be more credible to management because the estimates can be related back to a comparable baseline system. This relationship will provide the program manager

FIGURE 5
F/A-XX Component Rework, Replenishment Spares, Other Consumables Cost Estimates

	BENCHMARK SYSTEM					FA—XX SYSTEM		
Functional Element	Component Rework	Replen Spares	Other Consumables	$\overline{R}$ Scalar	Material Scalar	Component Rework	Replen Spares	Other Consumables
Structural Element (WUC 11,12,13)	$16.15	$10.99	$23.45	.71	2.27	$21.87	$14.89	$31.77
Power Plant & Installation (WUC 23,27,29)	$12.74	$ 2.76	$ 3.36	2.00	1.19	$37.61	$ 8.15	$ 9.92
Fuel Systems Hyd/Pneu (WUC 13,45,46)	$12.83	$ 7.28	$ 8.40	.65	2.27	$15.91	$ 9.02	$10.41
Elect & Wiring (WUC 42,44)	$ 4.48	$ .96	$ 5.99	.56	2.27	$ 4.79	$ 1.02	$ 6.40
Miscellaneous (WUC 41,47,49,91, 96,97)	$16.34	$ 3.02	$ 3.92	.77	2.27	$24.01	$ 4.44	$ 5.76
Instruments (WUC 51,56,57)	$20.07	$ 2.49	$ 4.57	.47	2.27	$18.00	$ 2.23	$ 4.09
Comm/Nav/Ident (WUC 63,64,65,67, 71,72)	$10.81	$ 1.06	$ 8.72	.34	1.95	$ 6.54	$ .64	$ 5.27
Offensive/Def (WUC 73,74,75, 76,77)	$60.17	$ 7.87	$19.83	.45	1.95	$48.20	$ 6.30	$15.88
TOTAL	$153.59	$36.43	$78.24			$176.93	$46.69	$89.50

NOTE Costs Per Flying Hour

with the capability to determine, in design- and logistics-related terms, the anticipated differences in O&S cost between the new and an existing system.

It is this attribute of O&S cost estimates that has been missing in the past. The VAMOSC data provides the needed credibility to convince the program manager that the calculated O&S cost impacts of program alternatives are reasonable, and therefore deserve consideration in the decision process. ‖

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Is Cost Growth Being Reinforced?

Noreen S. Bryan
Dr. Rolf Clark

Cost growth is a major problem in defense systems acquisition. In recent congressional hearings, Chairman Jack Brooks stated: "Since 1969 the DOD has underestimated costs of all major weapon systems by more than 50 percent."[1] Yet this is only half of the cost growth problem. What Chairman Brooks' committee was investigating was growth within a program—from the time of its initial planning estimate to actual delivery of production systems. There is another aspect of cost growth, namely the trend of increasing unit costs from one generation of systems to the next. We will need to deal with both of these aspects.

No single factor can be identified as the cause for the increased cost of military systems. Investigations of cost growth have identified inflation, technical changes, quantity decreases, overoptimism and "buy-ins," and reduced DOD budgets as major causes of cost growth and resultant increased unit cost of systems. Program management has been criticized for its lack of adequate control of contractors. Yet, even in aggregate, these well-known causes do not provide a complete picture.

There are also policy and management factors that are significant contributors to cost growth. In the hearings referenced, Jerome Stolarow hinted at some of the policy issues causing growth, but they were never developed beyond an *implication* that inflation, complexity, and other factors were being used merely as scapegoats to explain cost overruns. In this paper we will try to explain some of these complex policy and management issues that are not well understood. We leave the more traditional (but also valid) cost growth explanations for others to present.

1. "Inaccuracy of Department of Defense Weapons Acquisition Cost Estimates," Hearings before a subcommittee of the Committee on Government Operations, 96th Cong., 1st sess., June 25 and 26, 1979, p. 2.

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Interdependence of Actual Costs for Old Systems and Cost Estimates for New Systems

The history of cost growth for individual programs is abundant. Case histories for 18 Navy systems are provided in the Brooks hearings which show how much current system costs have risen above the initital estimates. But there is also the question of increased unit costs from one system to another—from the F-14 to the F-18 aircraft, for example, or from the Knox-class frigate to the Perry class. Review of unit costs shows a pattern that successor systems are indeed costing more. Table I shows examples of cost growth over time for acquisition of selected major systems.

Review of these examples shows increases in unit costs even after adjusting for inflation and weight. What are some of the causes, valid and not-so-valid, for such growth? First it is necessary to look at the methods for cost estimating. Common to all methods is the use of actual historical costs as the basis for projecting costs for a new system. Implicit in all the techniques is the assumption that what has occurred in the past is a good guide to what will occur in the future. The resulting forecasts of what will happen is based on the *assumption* that the same forces as have been operating in the past will continue to operate in the future. Thus, the cost trends we saw in unit cost histories for aircraft and ships in Table I are integral to the cost-estimating relationships and, inevitably, to expectations of the

TABLE I

Unit Costs, Adjusted for Inflation and for Size

Fighter Aircraft at Unit 200			Attack Aircraft at Unit 200			Frigate-Type Lead Ships		
(1981 $ per lb.)			(1981 $ per lb.)			(1981 $ per KTon)		
Year	Model	Cost	Year	Model	Cost	Year	Class	Cost
1956	F-8	$350	1953	A-4	$195	1963	Garcia	$11,500
1962	F-4	$360	1959	A-6[a]	$425	1968	Knox	$18,500
1970	F-14	$480	1965	A-7	$350	1978	Perry[b]	$35,000
1980	F/A-18	$700	1982	F/A-18	$700			

Notes: a. A-6 production rate was low (about 30 per year vs. 120 for the A-4 and 60 for the A-7) causing unit costs to be high comparatively.

b. The Perry-class frigate, being a guided-missile ship has been downward adjusted (based on fleet-wide data) for comparability with the Garcia and Knox, both non-missile ships.

costs of future systems. In fact, since the complexity of most of our military systems is continually increasing, one can conclude that the trend of increasing unit costs over time will continue in the future.

The Role of Increased "Ilities"

Disaggregation of the unit costs of systems into their components indicates that much of the unit cost increase is attributable to new "ilities" and management support requirements. Acquisition funds for fielded systems include not only the deliverable hardware units, but all of the support items—tests, engineering analyses, management functions, etc.—required for operational systems. Spares kits, training, and documentation are well-known examples of support items which are tangible deliverables like the weapon system itself. But there are additional support requirements that are levied on programs with outputs that affect the quality of a system, but which are not products in themselves. These support requirements include configuration management, integrated logistics support, habitability, system safety, human factors engineering, reliability, maintainability, design-to-cost and life-cycle-cost requirements, and an ever-growing list of others. These management support requirements have come to be known commonly as the "ilities."

As each of these "ilities" is added to the specification for a new system, the prime contractor assembles a team to perform the task. In addition, the government adds documentation requirements for plans, programs, technical reports and test reports. The contractor then adds the additional technical publication editors and illustrators to fulfill these requirements. The net result is the addition of a new staff of people. Further, the support of those support people must be coordinated into the design and fabrication of systems; added management responsibilities and personnel, and certainly added costs, are the result. Experience in evaluating proposals and return costs for Navy programs has shown that for each new support discipline, the addition of at least one person to the management team is required. Those teams that were once limited to a program manager and his assistants in financial and contractual management have now expanded to become unwieldy teams including 10 to 15 additional disciplines. The result of these additions of disciplines and people is to partition an ever-larger proportion of procurement dollars away from the weapon units delivered. Attacking this problem is particularly difficult because, while each discipline by itself adds only a small percentage of cost to a system, the aggregate effect of these added disciplines is significantly increased costs.

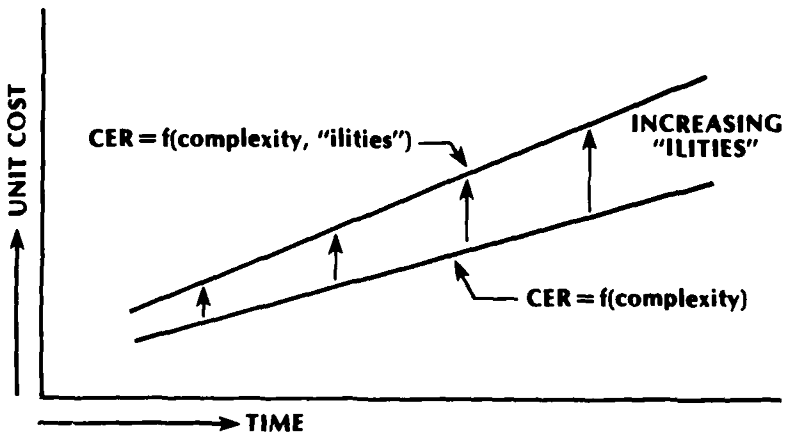
The "ilities" are necessary, or at least highly desirable. But at what cost? We question the addition of these "ilities" without a system to address their "value added." Typically, these trends of increasing "ilities" and support functions are not brought forward for review, but rather are treated as necessary implementations of government regulations and are built into the cost of subsequent systems.

Unlike in a profit-motivated organization, the check and balance system which asks what is the cost relative to the value received from each of these added disciplines is missing.

Within the cost area itself, cost schedule control systems criteria (C/SCSC) were established as a method to alert government management when performance under a specific contract was deviating significantly in cost or schedule. Too often, application of C/SCSC has resulted in an elaborate set of procedures which may not be worth their cost, particularly if the government management team is inadequately staffed to analyze and use the results. Typically, the implementation of C/SCSC has resulted in the expansion of the contractor's financial management team threefold to fivefold. A program that required two financial managers to track a program's cost and schedule progress prior to C/SCSC now requires from six to ten people.

Presuming that this pattern of cost increases is occurring, the question arises as to why evidence of these increases is not readily apparent in historical cost data. The answer involves the fact that most data is aggregated at too high a level to make these effects obvious. Additionally, estimating techniques, particularly parametric CERs, include the costs of the "ilities" as undefined components of the system complexity (i.e., physical or performance characteristics). As stated earlier, the complexity of most military systems has been increasing with time. Since the number and dollar magnitude of the "ilities" has also been increasing with time, the resulting CERs are composites of these two effects. Figure 1

FIGURE 1



demonstrates this concept. The "ilities" increase the upward trend of unit cost that is already increasing based on complexity.

Program Cost Growth—Motivation to Increase Cost Estimates

Program cost growth, as discussed by Chairman Brooks and his committee, has been a source of continued criticism by the Congress and the press. Certainly, the motivation created by this criticism is to try to reduce cost *growths* in the future. Cost estimators have responded by including allowances in cost estimates to cover cost uncertainties. These are typically added as factors such as an "engineering-change" factor, a "weight-growth" factor, a "productivity-loss" factor, an "allowance-for modification" factor, etc. The combined effect of these factor additions is an increase in the initial cost estimates. A first reaction might be that this added cost is an application of lessons learned from cost growth on earlier programs and will eliminate, or at least lower, cost growth in the future. This is partly true—there will tend to be less cost overrun above initial estimates. But we will argue that a concurrent effect is higher unit costs overall; that indeed an obverse cost policy has inadvertently come into existence. Instead of creating motivation to reduce unit costs, the attempt to eliminate cost growth effectively works to elevate the cost of delivered systems.

Unit Cost Increase for an Amphibious Ship Class

Why this is the net result is not obvious. It will be helpful to consider an actual example of how the "ilities" and cost uncertainty factors are incorporated in a cost estimate. This estimate will be compared to the actual costs of the predecessor system, and the impact on unit cost will be evaluated. Two amphibious ships will be compared. In one case it will be the *estimated costs* for a 1981-class ship; in the other it will be the *actual costs* for the 1965 ship, which is the last comparable class built. The details of the costs for each class are shown in Table II. A study of this table provides the following insights. In total, the cost estimate for the new amphibious ship is five to six times higher than the actual costs incurred for the earlier ship. When these numbers are adjusted for weight and inflation differences, the new ship has essentially doubled in cost (and this is only the estimate, not the actual cost). Acknowledging some differences in the two classes, this still seems a large rate of growth, and indeed some of the components in the cost estimate seem to have grown exorbitantly. Construction plans are up fourfold from the earlier-class ship; government-furnished electronics equipment up twofold; hull, mechanical, electrical equipment up threefold. Demands for system engineering and for habitability, previously implicit in the basic construction costs, now account for an additional 20 percent or so of the basic construction costs.

Those items already mentioned—system engineering, plans, government furnished equipment, and habitability—relate both to *increased* requirements for

TABLE II

Comparable Ship Costs Adjusted for Size Differences (Dollars in Millions)

Construction	A. 1965 Ship (1965 $)	B. 1965 Ship (1981 $)	C. 1981 Ship (1981 $)	C ÷ A	C ÷ B
Labor Material & Overhead	$28.1	$84.3	$94.0	3.35	1.1
(Overhead Rate)	(97%)	(97%)	(110%)	(1.13)	1.1
System Engineering Factor(R)	$ 0.0	$ 0.0	$12.8	∞	∞
Habitability Factor(R)	$ 0.0	$ 0.0	$ 2.8	∞	∞
Margin for Weight Growth(F)	$ 0.0	$ 0.0	$ 9.4	∞	∞
Profit (F)	$ 2.2 (8%)	$ 6.6	$17.8 (15%)	8.1	2.7
	$30.3	$90.9	$136.8	4.5	1.5
Other Costs					
Construction Plans(R)	$ 2.7	$ 8.1	$32.3	12.0	4.0
Change Orders (F)	$ 0.6	$ 1.8	$20.2	33.7	11.2
Government Furnished Equipment (R)					
Electronics	$ 0.7	$ 2.1	$ 3.8	5.4	1.8
Hull/Mech/Elect	$ 0.6	$ 1.8	$ 5.2	8.7	2.9
Test & Evaluation (R)	$ 0.0	$ 0.0	$ 3.0	∞	∞
Training (R)	$ 0.0	$ 0.0	$ 3.4	∞	∞
Misc. Other	$ 2.9	$ 8.7	$13.9	4.8	1.6
	$ 7.5	$22.5	$ 81.8	10.9	3.6
TOTAL COST	$37.8	$113.4	$218.6	5.8	1.9

NOTE: (R) = "Requirement"
(F) = "Uncertainty Factor"

technical performance and *new* requirements for "ilities" and management support items. In fact, there are more increases for "ilities" than appear on the surface. Currently, more than half of the system engineering costs are typically the sum of individual costs for "ilities," namely reliability, maintainability, safety, standardization, producibility, survivability/vulnerability, human factors, etc. And certainly the total costs for the "ilities" are not attributed to system engineering. Demonstration of the ship's ability to meet the "ilities" requirements results in an expansion of the test and evaluation (T&E) program. Referring to Table II, T&E is another area of cost that has increased significantly.

The categories of cost listed in Table II also show evidence of the "cost uncertainty" factors discussed previously. The "Margin for Weight Growth" category is a 10 percent factor added for unforeseen changes to the ship's weight. Another category, the "Allowance for Change Orders," has become a major cost driver. In an attempt to understand the magnitude of cost uncertainty factors, we have attempted to separate "requirements" categories from "cost uncertainty" ones (an-

notated accordingly in the table). In total, the cost uncertainty factors account for 17 percent of the 1981 ship cost. And this cost is only for those categories that are identifiable as allowance factors. In addition, there is evidence that a portion of the increases in the requirements categories relate to cost allowances so that "cost overruns" can be avoided. For example, system engineering is estimated using a factor chosen from a range. When this estimate was made, the 13.5 percent system engineering multiplier was the maximum used by ship estimators, yet this specific ship has apparently been touted as not being particularly complex. When used this way, the factors can drive up the unit cost of ships in an uncontrolled way.

In an environment without true management reserves, and one in which motivation is to have initial estimates match the eventual end costs of the system, the use of such "factors" becomes a necessity, an apparent method to hedge against cost growth. But, the practice can be overdone. The factor for change orders is one of particular concern. In the last 15 years, and especially since the great claims litigations of recent times, there has been emphasis to reduce changes. Ships are probably changed less now, yet there is a major allowance for changes in the 1981 ship, whereas it was minimal for the earlier class. As a percentage of the total ship costs, we are now estimating changes to be 10 percent of the total cost, while they were 2 percent of the previous class. Is that reasonable? Another allowance factor is the 15 percent productivity loss in labor efficiency that is not shown but which is factored into the basic construction cost of the 1981 ship. This productivity loss occurred in the past when shipbuilding declined in the United States. Should it be gained back as shipbuilding accelerates? The mere fact that productivity loss occurred should provide evidence that productivity gains may occur when economic factors feed back into the shipbuilding industry to make it less likely to lose more productivity. Is this productivity loss "trend" to be incorporated forever in the cost process? These are the types of questions that policy-makers must ask.

The intent here is not to single out problems in ship costs, but rather to provide examples of how cost factors arise as ways to compensate for past influences on growth. They occur in all systems. Nor can we blame cost estimators for trying to avoid the cost overruns of the past. In fact, current policy motivates them to make estimates high enough so that serious cost growth in a program will be avoided. But the attempts are, we offer, doomed to fail. For by avoiding cost growth in *a* program, we may be causing excessive growth in cost *between* programs, the result being an extension of the trend of increasing unit cost. We turn to that dilemma.

The Cost Spiral—The Interaction of Cost Estimates in the Acquisition Process

We have looked at how future cost estimates are based on past cost histories and have seen examples of how cost histories are incorporated into estimating

methods and support increased unit costs of Navy systems. We will next consider how these estimates are converted into expenditures and investigate how this process affects unit costs.

The estimator projects the cost of the new system based on the "end costs" of the predecessor system. "End cost" means that *all* the costs associated with the earlier system are included—not just the costs envisioned initially, but also the added costs accumulated during the research, development, and production phases. These added costs can be significant. Navy systems typically go through iterative technical changes, some the result of new operational requirements, others the response to needed corrections, still others the effect of technological breakthroughs made on subsystems during the acquisition phase. Actual costs include all these iterations, the scrapping of plans, drawings, modules of hardware and software, and the addition of new plans, etc.

Let's look at how these estimates fold into the process of acquiring new systems. Estimates become program budgets, and program budgets become funds that government project managers expect to expend to buy systems. If the project manager, believing that these funds represent probable "end costs" for the new system, attempts to procure the system within these bounds, then clearly he needs *to set aside some amount of money (i.e., management reserve)* to cover the unknown but inevitable changes. However, the establishment of a management reserve is contrary to prescribed policy for budgeting and obligating funds. Regardless of the type of funding, the program manager is operating under pressure to obligate the authorized funds within about 12 to 15 months. But contractual regulations preclude the program manager from obligating money for undefined tasks; hence, the program manager cannot establish a "set-aside" budget or incorporate a management reserve in his contracts with prime suppliers.[2] The cost estimate may, as in the ship case discussed above, set aside factors for program changes, for weight changes, etc., apparently similar to "reserves." But once a program is authorized with these reserve factors included, and once budgets are formed, the system will be designed to that entire authorization number, and the reserves for changes will be absorbed in the design. None will be left over for unanticipated changes.

Consequently, funding meant to be adequate for the completed system, i.e., "end cost," becomes the start cost instead. So system designers, both government

2. We must be careful about what is meant by the term "management reserves." Management reserves set aside by contractors as part of the planning and distribution of funds within their organization are not to be confused with the government management reserves discussed in this paper. The contractor's management reserves are used in the performance of the work that is within the scope of the contract. The government management reserves, on the other hand, relate to new requirements that are outside the scope of the contract and must be added later through separate contractual actions.

and contractor, initiate the program by designing a system at inception to absorb the total resources estimated for the completed system. Then, when undefined changes occur, their costs must be added through reprogramming from other sources (i.e., either other programs must be sacrificed, or quantities must be reduced). Both actions raise unit costs again, and affect future unit costs as well. When the systems are finally delivered as production units, the total actual costs are once more significantly higher than the original estimate. The conclusion is that once again the Navy has failed to adequately estimate the costs. Certainly, as a minimum, the new data point for this system's cost must be added to the history of data points from previous systems, with the result that the trend that was already increasing will be accelerated at a more rapid rate. In reality, the cost growth problem is not inaccurate cost estimating, but rather a system that attempts to predict end costs, but which does not allow management to these costs. Restraining added requirements, acknowledging that add-ons will occur, and then having management reserves to cover the necessary add-ons are needed.

The cost spiral is one of repeating cycles of estimates, program budgets based on the estimates, and contracts keyed to program budgets. It is a complex spiral. *Estimating higher to acknowledge past overruns seems reasonable.* Basing budgets on estimates seems reasonable; designing to the budget seems reasonable. Yet because system design is keyed to the funding available, and because changes are inevitable, the composite *effect is inevitable cost overrun.* This cyclical pattern is shown by the flow diagram in Figure 2. A quantification of one cycle is shown in Figure 3.

In order to explain the concept of the cost spiral and understand how it works, it has been necessary to simplify the acquisition process (and, in some ways, to oversimplify it). Certainly, there are many complex actions and policies that are interacting concurrently. For example, in our description of the cycle, it has been presumed that the costs of new systems are budgeted at the value that is projected by the cost-estimating relationship. Experience indicates that this is not always true. Other forces, such as constrained resources, or excessive optimism about the facility of achieving technical requirements, cause the initial estimates to be budgeted below the predicted value. Referring to Figure 3, the initial estimate may be artificially optimistic, and be much closer to the cost of the predecessor system (System 4 on the chart). Despite this fact, however, the events that follow the initial budgeting will still occur as we have described them, and in fact translate into similar *proportional* cost growth. Systems are designed to utilize *all* the costs that are initially budgeted. Changes and new requirements occurring subsequently still become "added costs" to the program. The program cost growth such as that observed by the Brooks hearings will still occur—and the motivation to avoid such cost overruns will be built into future estimates once again.

FIGURE 2
The Evolution of Cost Growth

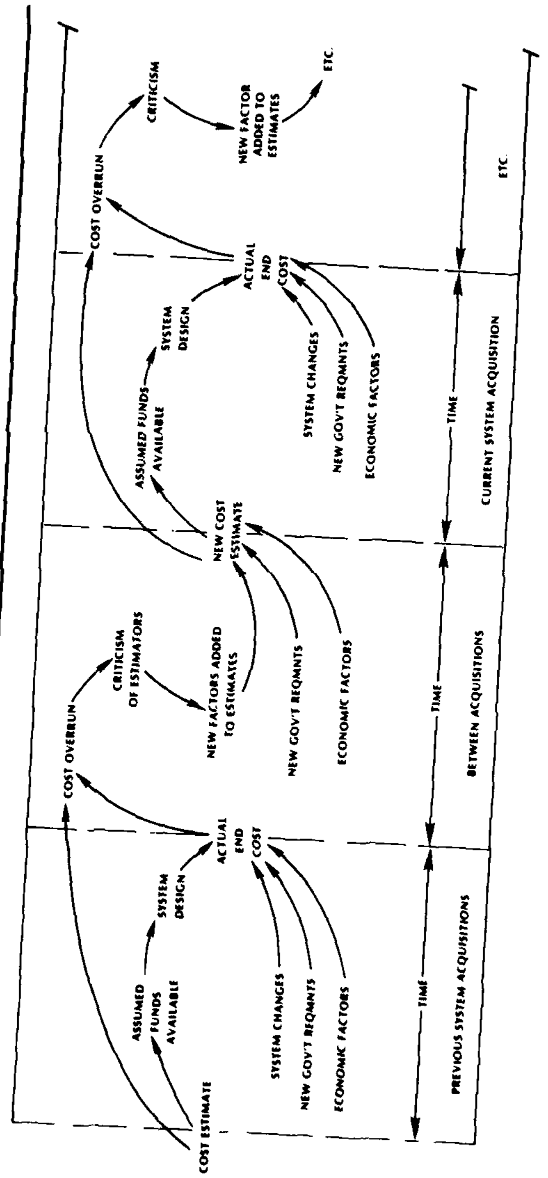
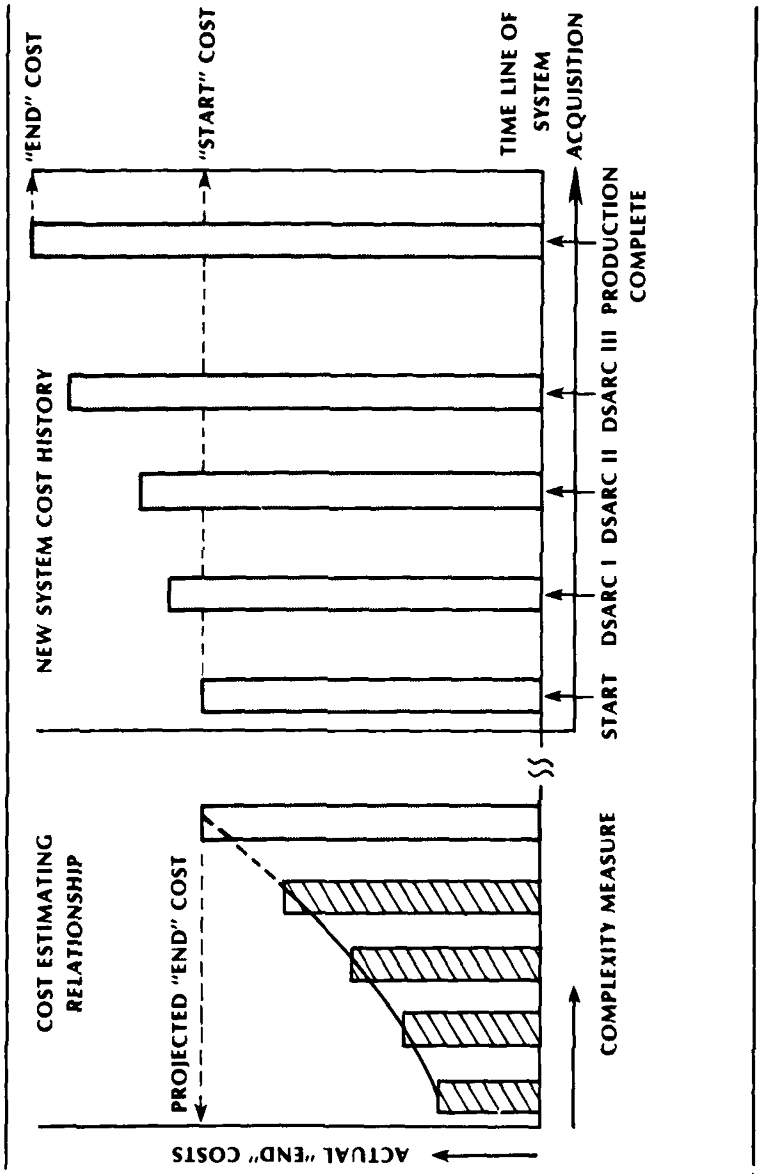


FIGURE 3


COST ESTIMATING RELATIONSHIP
PROJECTED "END" COST
ACTUAL "END" COSTS
COMPLEXITY MEASURE
NEW SYSTEM COST HISTORY
"END" COST
"START" COST
TIME LINE OF SYSTEM ACQUISITION
START
DSARC I
DSARC II
DSARC III
PRODUCTION COMPLETE

The Trade-off Between Program Cost Overruns and the Growth in Cost Estimates

It would appear that to restrain cost estimates to less than the established cost trend would only ensure larger cost overruns in the future. That is true, but the end cost of systems might be less, too. In other words, while the cost growth between a well-controlled estimate and the final end cost may be higher, it is also true that the ultimate end cost of the system could be lower than if the estimate simply followed the cost trend. The following hypothetical example applies.

	End Cost of Previous System (A)	Initial Estimate (B)	End Cost of System (C)	Growth Between Systems (B + A)	Program Cost Growth (C + B)
A. Cost Trend Estimate	100	200	220	100%	10%
B. Well-Controlled Estimate	100	120	180	20%	50%

In case A, the growth in cost from estimate to end cost is only 10 percent, while in B it is 50 percent. Current policy makes case A a more acceptable alternative for the cost estimator and program manager. While the system costs much more, the *visible* cost error—that is, the percent increase of end cost over the initial cost estimate—is much less. Under present policy, cost estimators and program managers will opt for case A.

What Can Be Done?

Awareness of the cost dynamics, the spiral described, is the first step. What is needed is a new approach to cost policy—one which brings to bear the various disciplines of the management community to sort out those categories of cost which are *essential* from those which are *allowed* because estimates are based on increasing CERs and trends rather than examination of these trends. Program managers, contracting officers, auditors, and especially the cost analysts, must come to understand the cost dynamics, and how to retard their growth. Critical review is needed of the trend underlying the estimates. Management procedures which require addition of support requirements without concern for "value added" need to be scrutinized.

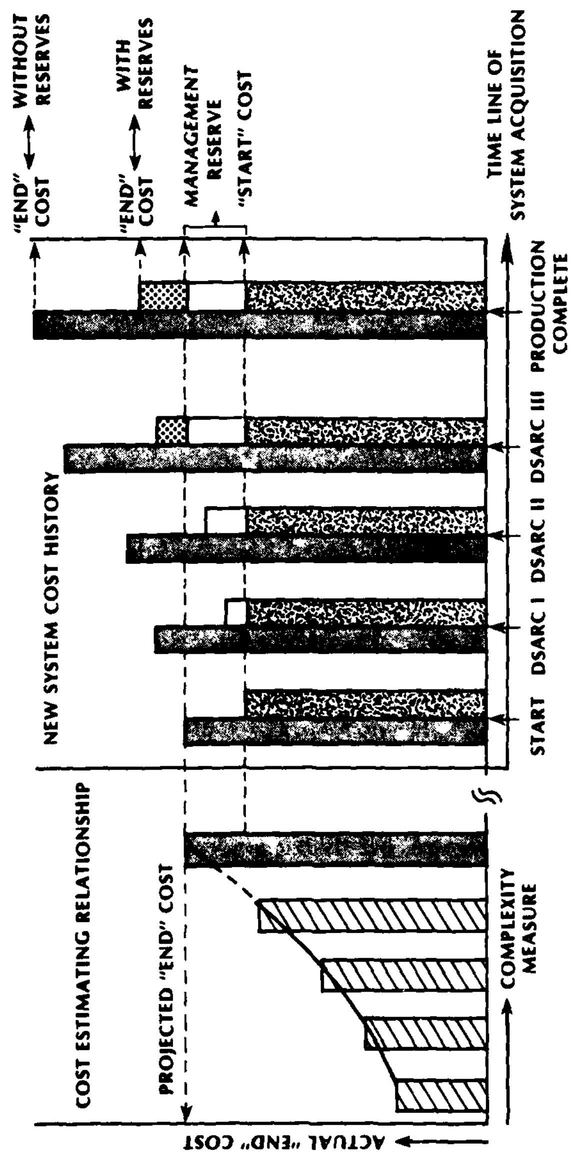
In order to perform adequate cost control, the present separation of the cost analysis community from the contracting and auditing community needs to be eliminated. Cost estimators must come to understand the details of project management, of manufacturing, and of contractor accounting, so that they can isolate *necessary* cost growth factors from those that are merely being trended. If habitability is an essential category to retain sailors in the fleet, then the increased costs for this item should remain in cost estimates. But "trending" increased overhead rates, without understanding that unused capacity is being *encouraged* by those overhead trend lines, should be made unacceptable. Costs probably cannot be reduced in the future. But the growth lines can be made to grow in a decelerating path, rather than an exponentially accelerating one.

There needs to be an understanding that program cost growth will occur—that there is a trade-off. A low but reasonable estimate for a project will result in greater program cost growth than will occur if the estimate is too high. The higher estimate may save embarrassment to the program manager and cost estimator, but excessively high estimates may also lead to higher end costs for the program. One trades off *total* program cost from one program to the next for program cost *growth* from the initial estimate to the end cost.

One key to avoiding this dilemma lies in the intelligent use of management reserves. We can suggest that reserves must be programmed, but they should be retained centrally and not become identified with a specific project. The reason is obvious: Once identified with program X, the project manager and the contractors cannot help but to *plan* on that reserve being available, and designs will evolve accordingly. On the other hand, if reserves are kept centrally, then the system design will not evolve with the reserves essentially "built-in," yet valid needs can still be filled when they do arise. One will be less likely to spend funding which only *might* be available, than to spend funds which *are* available. Figure 4 provides the graphics on the resulting reduction in the cost growth of Figure 3 when management reserves exist. There will still be overruns, probably in excess of reserves (as shown), but the net result would be a system that costs less.

The cost community is well-equipped, intellectually, to understand the various aspects—analytical, production, contractual, managerial—which must be integrated to control costs. They understand the trends which must be accounted for, and they have the analytic talent to sort out those trends that are unavoidable from those that are not. Indeed, hardly anywhere else will there exist the proper mix of analytic talent, engineering experience, pricing experience, project experience, and contracting knowledge. What is needed to bring these talents to bear is a cost policy change which emphasizes the search for the reasons of cost growth, and slows the urge to perpetuate trends.||

FIGURE 4


COST ESTIMATING RELATIONSHIP
PROJECTED "END" COST
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ACTUAL "END" COST
NEW SYSTEM COST HISTORY
START
DSARC I
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PRODUCTION COMPLETE
TIME LINE OF SYSTEM ACQUISITION
"END" COST
WITHOUT RESERVES
"END" COST
WITH RESERVES
MANAGEMENT RESERVE
"START" COST

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Meeting the Challenge of Multinational Programs

Major Michael J. Rendine, USAF

The increasing expense of acquiring military systems, coupled with unfavorable economic and political conditions, has caused most industrialized nations to expect coproduction offset as a condition of foreign military sales (FMS). Consequently, U.S. Government programs with potential for foreign military sales also have potential as multinational coproduction efforts. The size of the F-16 program, in terms of dollars and complexity, proves the validity of this concept and serves as a model for the future.

Successfully producing aircraft components in five countries, with final assembly in three countries, is recognized as a significant technical achievement. The financial management of such a program, however, is usually viewed as a bookkeeping nightmare rather than as a challenging opportunity for a unique and rewarding experience. People not familiar with the F-16 program focus on the cost-accounting complexity, imagining rows of "bean counters" slaving over their calculators, producing reams of billing information. Actually, there are surprisingly few people within the systems program office who are engaged in the financial management of the program. And the center of their activity is not accountability, but the unique econometric issues that are the heart of the multinational consortium.

This paper will address the critical financial challenges of the F-16 multinational program. The basic economic tools necessary to deal with these challenges will be considered, as will the interrelationships established to bring these solutions together in a rational application. Finally, I will discuss the problem of "how to get there" on any multinational program.

The Challenge

The F-16 memorandum of understanding (MOU), signed at the Secretary of Defense level by the United States, the Netherlands, Belgium, Norway, and Denmark, stipulates that the industries of the five nations shall be insulated from potential losses or gains caused by inflation or fluctuations in currency exchange rates. This premise is essential because the multinational consortium is an intergovernmental organization that is not in a position to commit industries to money-losing propositions. The stipulation triggered unique currency exchange

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provisions and national/multinational indexing of industry costs. The existence of inflation indices, however, begs the question of determining program costs in terms of the time value of money. The MOU addresses this issue by stipulating that the European participating government aircraft shall have not-to-exceed target cost of $6.091 million as measured in 1975 base-year dollars. The base-year-dollars concept was applied to synchronize the congressional/parliamentary budget basis within each country. The use of 1975 dollars allowed the cost of the program to be established in (at that time) current-year dollars, while affording each country the budgetary flexibility to address then-year dollars in their own governmental manner, which differs among the five nations. The upshot is that the letters of offer and acceptance, contractual documents between the U.S. Government and each of the European governments, are denominated wholly in 1975 base-year dollars. In addition, for economic and industrial purposes, each letter of agreement contains over 40 individually priced subcases, which is two to three times the number of subcases in a conventional foreign military sales program.

On the U.S. side, both DOD and the Congress recognized the potential cost savings of producing a large quantity of aircraft (348 for the Europeans, 650 for the U.S. Air Force) as well as the potential for increased cost owing to multiple manufacturing/assembly locations, initial investments, learning curves, and the cost premiums associated with European work. To ensure that the taxpayer would not pay a higher cost for a consortium F-16 (998 aircraft produced) than for an all-domestic program (650 aircraft only), which would be a violation of public law, an impact of coproduction report is required with each annual U.S. Air Force F-16 budget submittal to Congress. The intent of this report is to compare the actual program against a giant "what if"—what if there were no coproduction program, and the U.S. Air Force F-16's were built domestically? The ability to continue to project the cost of a hypothetical program in a credible manner rests upon the competence of the estimators and their grasp of the econometric principles involved.

Two subcommittees of the F-16 Steering Committee oversee and assist the financial manager in defining and developing solutions to the above requirements. They are the Contractual and Financial Subcommittee, composed of military representatives of the five air forces; and the Subcommittee on Industrial Matters, primarily made up of civilians from the various ministries of economics. In addition, 24 cost-sharing/allocation accords are in force multinationally.

With considerable visibility, and motivated by fundamental elements of the MOU and multigovernmental requirements, the F-16 proceeded to deal with currency exchange protection, multinational inflation, base-year dollar tracking, and impact (cost/benefit) of coproduction. These challenges may be new to the DOD financial manager, but the solutions merely require application of basic econometrics, which run consistently through each of the four challenges.

Currency Exchange Protection

The F-16 contracts/subcontracts/purchase orders are denominated in the domestic currency of the seller. If a U.S. prime contractor purchases a component from a Dutch firm, the contract is written in Holland florins. Likewise, if the Dutch firm establishes a purchase order with a Belgian firm for raw material from which the component will be manufactured, the purchase order will be priced in Belgian francs. Although this results in thousands of contractual instruments denominated in each currency, stability is achieved through MOU-stipulated fixed rates of currency exchange. Thus, the value of all instruments can be summed up in U.S. dollars by applying the fixed rates. The contractors obtain the currencies to pay one another from the F-16 Currency Clearing House, utilizing the fixed rates of exchange. Because the contractors obtain currencies at a fixed rate, regardless of open-market rates, they are insulated from gains or losses resulting from currency fluctuations. The five governments, however, obtain currencies at the market rates to supply the currency clearing house. Thus, the governments bear the currency costs or reap the benefits, just as any government contends with the cost of inflation when purchasing defense materials. To operate a currency clearing house, the financial manager needs more than currency and a good financial record system. Proper operation requires knowledge of the value (then-year) expenditure profile of each instrument so sufficient currency reserves are on hand. Knowing "how much" and "when" is the key to the currency clearing house, and is a common requirement of the next challenge.

Multinational Inflation

Financial managers are intimately familiar with the OSD indices used to represent a cross-section of U.S. inflation. Application of general indices to the F-16 program was unacceptable, because the MOU stipulates that *each industry* must be insulated from abnormal economic escalation. Thus, individual treatment of each coproducer is required with tailored indices. Under a multinational accord, each country provides specific labor and material indices (both projections and actuals as they occur) published on a semiannual basis. To properly apply these indices, the base-year value of work performed by each industry for each half-year interval of the program (1976-85) must be known in terms of both labor and material (domestic/non-domestic).

Contractors are protected from the effects of inflation by comparing the projected inflation index assumed in the contract to the actual inflation index experienced. Significant differences, positive or negative, are corrected by an economic price adjustment to each contract on a semiannual basis. It is to be hoped that the index, or indices, selected is a representative proxy for actual inflation.

The total summation of all indices, weighted by the work performed by each affected industry element, results in the F-16 multinational fighter program index. The index is updated each half year to adjust for engineering changes, new work (simulators, trainers, spares, etc.), as well as the revised national indices. The revisions accumulate the economic price adjustments with the index, providing then-year/base-year integrity. The task of making these adjustments has been computerized, with a savings of 2 man-years per semiannual update, and a reduction in processing time from 6 months to 1 week. The principal elements are "how much" (work) and "when" (semiannually).

Base-Year Dollar Tracking

The harsh realities of present-day economics demand quick payment of contractor expenses, with the time value of money fluctuating recently between 10 and 20 percent. Although the contractors are paid in then-year dollars, a methodology was required to establish the base-year-dollar value of every expenditure. Since all 40 subcases for each of the four European letters of agreement are priced in base-year dollars, the then-year value is a function of how fast the base-year dollars are expended, and the prevailing inflation rate. The overall "system requirements" for F-16 financial management involved evaluating all expenditures (then-year dollars), including economic price adjustments against 160 subcases (4 countries X 40 cases), de-escalating to base-year, and applying to 160 respective base-year-dollar subcases. An automated case management system computer program accomplishes this task for the F-16. Financial managers input actual then-year dollar expenditures into each then-year case, and make adjustments in base-year dollars to the base-year case expenditure profile. Differences in estimated vs. actual expenditures (base-year dollars) are "spread" in future quarters, and each case is re-escalated to arrive at a new then-year-dollar value; while the base-year-dollar case value remains constant. Although this may appear as computer magic, it is an application of "how much" and "when." If the value of each disbursement is known over time, keeping track in 320 subcases (160 base-year, 160 then-year) is another computer problem. The principles of "how much" and "when" remain the same.

Impacts of Coproduction

The almost overwhelming task of deriving the costs/benefits of coproduction can be defined simply. So far, certain data bases have been defined to solve previous challenges. These data bases include information concerning work performed under every contractual instrument for each industry, broken out by labor and material over 6-month increments, the prevailing inflation rates of each industry, and expenditure rates over time. If additional information is added to this data base, new capabilities can be created.

The new capability required is the ability to econometrically model each domestic and European industry. The information required includes, but is not limited to, overhead pools, business basis, and learning curve.

Given this information, on a mathematical model basis, all European effort can be removed from those industries and re-priced under domestic conditions. In addition, overall domestic effort can be reduced from 998 aircraft to the 650 aircraft, U.S. Air Force-only program. With this information, the estimated "what if" price can be developed. Certain other non-model data, such as recoupments for research and development, must also be added to complete the impact analysis. Because new actual data (then-year) is available every year, but the target estimates are base-year, the capability to translate base-year/then-year must always be present.

The impact of the coproduction task can be overcome by utilizing the previous "how much" and "when" information, plus new information on an industry-specific basis. Although oversimplified, and stretching the "how much" and "when" philosophy to its limits, this new information fits the mold.

Interrelationships and Rational Applications

Figure 1 is an attempt to schematically define the interrelationship of these econometric elements. Following the figure, the governmental labor and material indices are applied against the work distributions throughout the program. This results in the F-16 multinational fighter program index. Reapplying the index to any new work will define the overall amount of currency required within the currency clearing house for currency exchange (offset being a base-year value). The then-year-dollar expenditure profiles (work distribution over time) can be used to break down the anticipated currency clearing house requirements by quarter. Overall actual subcase expenditure (then-year dollars including economic price adjustment) are de-escalated by the multinational fighter program indices to provide base-year dollar equivalents for the base-year track of the automated case management system. The distribution of work by industry, plus additional industry econometric data, provides the basis for the impact of coproduction model, with multinational fighter program indices used to normalize base-year/then-year actuals and projections.

Although not totally utilized to date within the F-16 system program office, the rationalized elements can be worked together in an integrated system. Within the F-16 program many of the software systems and data bases were developed independently because system requirements were defined as managers worked to solve a particular problem. The evolutionary nature of the solutions may make a totally integrated system overly complex and insensitive to change. Therefore, integration may require development of the overall system specification in advance; however, the basic philosophies still apply.

FIGURE 1

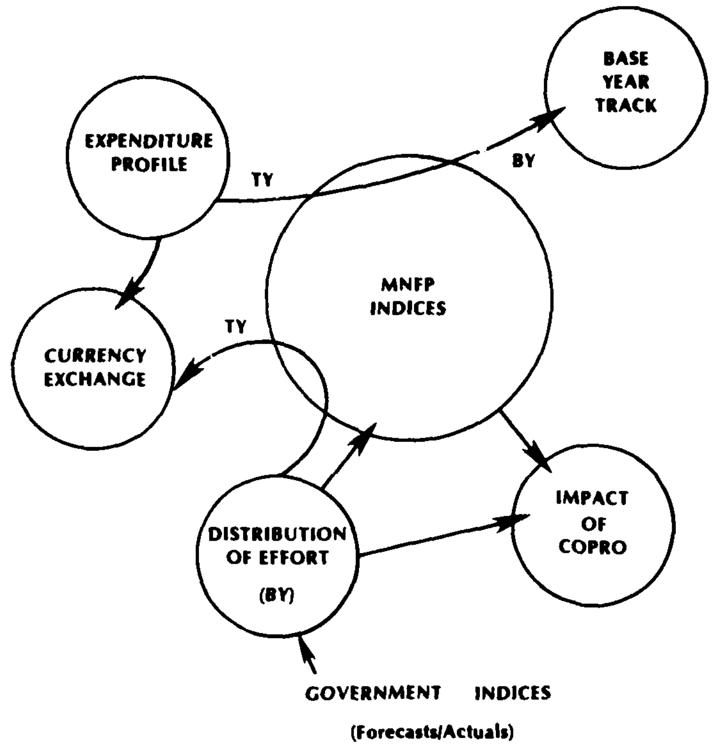

Table I is a generalized data table that attempts to rationalize data-base requirements and summarize the econometric areas a multinational program should anticipate entering. If this table appears simple, perhaps it is because the concept isn't as complicated as might be expected. Many of the data elements are used during prime contractor negotiations, or after contract award. The significant difference within a multinational coproduction program is that these data elements must be expanded to the subcontract/vendor level.

How to Get There

In the process of identifying the fundamental econometr[illegible]ls necessary for multinational financial management, many unique computer-driven accounting efforts were glossed over as mere mathematical exercises. In reality, these com-

TABLE I
Data Table

CHALLENGE	CRITERIA	HOW MUCH	WHEN
Currency	Per Contractor	Purchase Order Value	Quarterly Expenditure Profile
Inflation	Per National Industry	Effort Labor Material	Semiannual Over Time
Base-Year Dollars	Per Subcase	Then-Year Dollar Disbursements	Quarterly
Impact of Coproduction	Per Component	Unit Cost Business Base Overhead Pool Learning Curve	Per Option Semiannual Semiannual Log Units

puter solutions were the result of months of codifying, system requirement definition, algorithm development and writing, loading, and debugging of programs. Clearly this is too much to ask of the most time-pressed financial managers, estimators, and budget analysts. The key to "how to get there" is the simple application of the existing science of operations research to the financial office. Within the Program Control Directorate of the F-16, operations research specialists and acquisition management officers work on an integrated basis with financial managers. Acquisition managers holding master of business administration degrees (with economic concentration) serve as a bridge between conventional financial procedures and the applied science of operations research. F-16 experience has shown that these three backgrounds (and dedicated people) can overcome the most persistent and complex problems, and minimize manpower requirements. Programs are constantly under revision to streamline, add capability, or reduce run time. A large majority of the programs are written in-house during the development process. The largest and most complex are written in final form or from scratch by commercial programming contractors.

The Air Force Academy firstclassmen summer research program was also an extremely effective and economical way to extend operations research and econometric talents. As many as six cadets per year contributed sophisticated and rigorous computer-aided solutions to the data base. The large majority of these

computer programs are available for use in other acquisition projects. The probability of direct application with no modification is small. With or without existing software, however, solutions to multinational financial management challenges exist through the mixing of disciplines and sciences.

Summary

The emergence of multinational programs brings with it an amplification of current tasks and a number of new efforts. The amplified tasks relate to the data base normally required for any major weapon system prime contract. Both contractual data and pre-award negotiation information are required fully on all subcontracts for multinational programs, with matching government data (inflation). New elements such as currency management and base-year-dollar management will be challenging but will not fall outside the realm of good business practices. The key element is the blending of the amplified current work and new, unique efforts together in a rational manner.

The cornerstone of the F-16 in this regard has been the integration of operations research personnel and business management personnel (M.B.A. with econometric concentration) within the conventional program control environment. This interdisciplinary approach has been responsible for highly effective solutions to unique, multidimensional problems.

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Overview of Cost Analysis in the Navy

John S. Nieroski
Carl R. Wilbourn

In February of 1970, the General Accounting Office (GAO) reviewed the acquisition of major weapon systems and noted that substantial cost growth was occurring on many ongoing programs. By March 1971, the GAO was reporting that the Department of Defense (DOD) had made a good start toward identifying the causes of this cost growth. Among the causes were (listed in order of importance) estimating errors, engineering changes, economic changes, schedule changes, net quantity changes, and support changes. A GAO report of theory and practices of cost estimating for major acquisitions showed that serious problems existed in cost estimating and suggested basic criteria that should be used in preparing estimates. The Department of Defense (DOD) concurred with the GAO finding and stated that corrective actions had been taken, i.e., the establishment of Defense Systems Acquisition Review Council (DSARC), and cost estimating and review groups at service headquarters and system command levels. This paper will describe the role, mission, and functions of the Resource Analysis Branch (Op-96D) as a participant in the Navy weapon system acquisition review process and Cost Analysis Program.

Cost analysis in the Navy in the past 10 years has evolved through the issue of directives and instructions into the cost analysis program, which defines responsibilities and procedures for estimating the costs of acquisition and ownership of Navy weapon and support systems, and for reviewing and validating such cost estimates. The purpose of the cost analysis program is to provide decision-makers the best program cost estimates and assessments possible.

The impetus for parametric cost analysis in the military services occurred in December 1971, when Deputy Secretary of Defense David Packard sent a memorandum to the secretaries of the military departments concerning two historically significant cost analysis initiatives. Mr. Packard requested that each military department perform an independent parametric cost analysis on each major weapon system at key decision points, and make the analysis available for each Defense Systems Acquisition Review Council review. The second initiative was to identify the steps the military secretaries were taking to improve the

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capability to perform independent parametric cost analysis, and to use them in acquisition management.

In January 1972, Secretary of Defense Melvin Laird sent a memorandum to the secretaries of the military departments, stating that "it would appear that each Service Secretary should have a staff component capable of preparing independent parametric cost estimates." This component should be responsible to the service secretary and organizationally separate from program proponents.

For several years prior to 1971 a modest cost review and analysis staff existed on the Department of the Navy Secretarial Staff. This organization was officially established in January 1972, and was called the Cost Review and Analysis Directorate. It reported to the Assistant Secretary of the Navy for Financial Management (ASN[FM]) and was responsible for critical review of cost estimates, including selected major weapon systems acquisitions. The Chief of Naval Operations, recognizing the need for an independent cost-estimating group on the OPNAV staff, issued a memorandum in June 1971. The memorandum directed the establishment of an OPNAV cost estimating and review group, entitled the Resource Analysis Branch (Op-96D), in the Systems Analysis Division (Op-96), within the Navy Program Planning Directorate (Op-090). In October 1971, the position of Chief of Naval Operations (CNO) Advisor for Resource Analysis was established, and was designated the head of the Resource Analysis Branch (Op-96D).

The Secretary of the Navy (SECNAV) issued SECNAVINST 7000.19 in October 1972, establishing the Department of the Navy cost analysis program. The purpose of this instruction was to promulgate policy on cost estimating throughout the Department of the Navy, and to assign responsibilities for estimating, validating, and reviewing the cost-analysis program. The cost-analysis program applies to all organizations within and supporting the Navy that are involved in the planning, programming, and budgeting process associated with weapon systems, forces, and support activities. One of the major functions of the Navy cost analysis program is to support the weapon systems acquisition review process by providing weapon system life-cycle-cost estimates and assessments at each milestone review. The SECNAVINST was reissued in March 1975 as SECNAVINST 7000.19B.

The Chief of Naval Operations issued OPNAVINST 7000.17, "Cost Analysis," in January 1973. This instruction provided policy guidance for implementation of the Navy cost-analysis program, and established a three-level evaluation process for Navy cost estimates. In the acquisition of new weapon systems and equipment, cost estimates are prepared by the Naval systems commands for review at the Chief of Naval Material (CNM) level, the CNO level, and the SECNAV level. The instruction was reissued in September 1975 as OPNAVINST 7000.17A.

In May 1973, SECNAVINST 5420.172 established the Department of the Navy Systems Acquisition Review Council (DNSARC) to provide a formal

mechanism for the Secretary of the Navy to receive the counsel of his principal advisors before making decisions concerning initiation or continuation of, or substantial change to, major weapon systems acquisition programs. The DNSARC also provides a forum for review of major weapon system acquisition presentations to be made to the Office of the Secretary of Defense. The SECNAVINST was reissued in May 1976 as SECNAVINST 5420.172B.

In October 1975, the Cost Review and Analysis Directorate merged into Op-96D, and the CNO Advisor for Resource Analysis became the SECNAV/CNO Advisor for Resource Analysis. This change made the position "double-hatted," reporting to the SECNAV through the ASN(FM), and to the CNO through the Director, Systems Analysis Division (Op-96).

The position of CNM Advisor for Cost Analysis/Estimating (NMAT-016) was established in October 1977. The CNM Advisor acts as a special assistant to the CNM in matters of cost analysis/estimating and associated policy, and represents the CNM in meetings on weapon system costs and cost-estimating functions in the systems commands, OPNAV, and OSD.

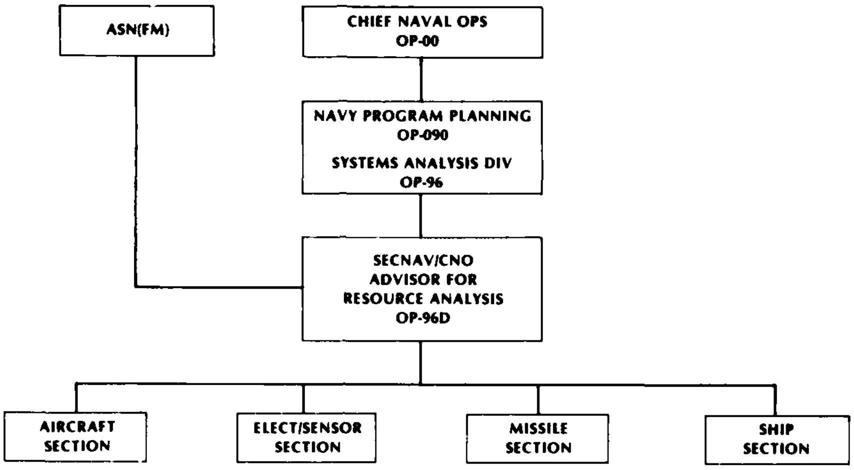
Role of Op-96D in the Navy Cost Analysis Program

The SECNAV/CNO Advisor for Resource Analysis directs a staff of 10 professional civilian and military cost analysts organized into four sections: aircraft, electronic/sensor, missile, and ship. Each section has a section head and one or two cost analysts. An organization chart, Figure 1, shows the relationship of the Resource Analysis Branch (Op-96D) to the CNO and ASN(FM). It should be noted that the SECNAV/CNO Advisor is also the Branch Head of Op-96D.

The SECNAV/CNO Advisor is the senior authority on cost analysis within the Offices of the Secretary of the Navy and the Chief of Naval Operations. The SECNAV/CNO Advisor and his staff (Op-96D) generate and provide an independent estimate and assessment of life-cycle costs of major weapon system acquisitions during major milestone reviews (DSARC 0, I, II, III). This independent cost estimate/assessment is usually based upon parametric techniques that are generally different from the techniques used by project managers. "Independent cost estimate/assessment" means the cost analysis group is organizationally separate from program proponents: and that the group is not a proponent or an opponent of the weapon system acquisition. The SECNAV/CNO Advisor provides a critical review and analysis of cost, schedules, performance, and other pertinent financial management aspects of major Navy programs for the CNO and ASN(FM) prior to the DNSARC proceedings. The objective of the independent estimate/assessment is to advise decision-makers on the reasonableness of the project manager's/systems command life-cycle-cost estimates.

In addition to generating an independent life-cycle-cost estimate/assessment for each weapon system/support system in the acquisition process, the Op-96D staff performs the following functions:

FIGURE 1
Resource Analysis Branch (OP-96D)



—Develops weapon systems cost models; develops and validates cost estimating relationships for major weapon systems and maintains their currency; and develops methodology, techniques, and criteria to be used in analyzing proposed weapons and evaluating the cost of alternative courses of action.
—Analyzes cost estimates for cost-effectiveness analyses, and works closely with groups that perform effectiveness analyses to ensure that all costs attributable to the systems (both direct and indirect) have been included in the analyses.
—Performs independent economic evaluations and cost-sensitivity analyses on major weapon systems.
—Ensures that all costs are displayed in a weapon system cost estimate, e.g., total life-cycle cost, at the OPNAV level.
—Reviews program documentation, such as the decision coordinating paper (DCP), operational requirement (OR), and mission element need statement (MENS), to ensure that resource annexes are consistent with current Navy program estimates.
—Recommends to the directors of special studies the cost techniques to be used, and the type of cost analyses to be performed in order to achieve the objectives of the study effort. Reviews studies and analyses from the cost viewpoint to examine relevance and impact of assumptions and conclusions, and determines the adequacy and validity of analytical methods and techniques used.

—Determines, with the assistance of the Chief of Naval Material activities and through liaison with Navy components, OSD, and contractors, the sources of cost data; defines and directs plans for acquisition and interpretation of the data; establishes a weapon-systems data base; and uses them to independently evaluate cost estimates forwarded to the CNO and SECNAV.
—Presents the independent parametric cost estimates/analyses to the OSD Cost Analysis Improvement Group (CAIG) at program major milestones reviews.
—Represents the Department of the Navy as the senior representative to the CAIG, and coordinates Navy and CAIG actions.
—Generates life-cycle-cost estimates or assessments for programs delegated to a DNSARC or CEB review level.
—Provides policy direction, guidelines, and advice to Navy activities on the development of cost-analysis procedures.

Role of the Project Manager in the Program Review Cycle

The weapon system acquisition review process is not a one-time event for a major program. The project manager knows that the program will cycle through the review process at least four times; that is, DSARC 0, I, II, III, going from concept formulation to production and deployment.

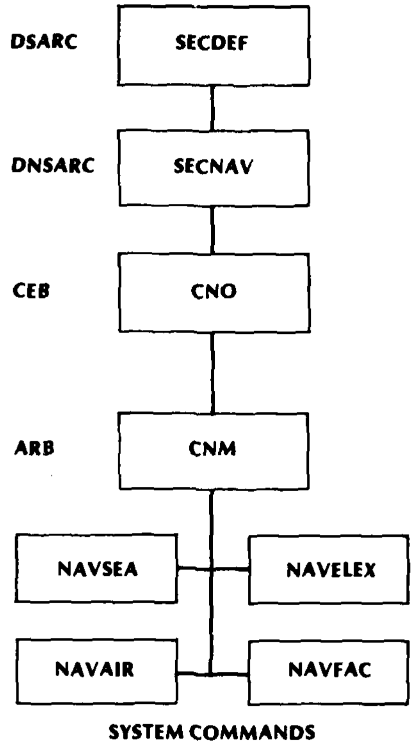
When a major weapon system is scheduled for a DSARC milestone decision review, a series of preparatory activities are initiated within the Navy. Various organizations in OSD, OPNAV, the Naval Material Command (NAVMAT), and system command headquarters coordinate their schedules to determine an appropriate DSARC meeting date and prepare the required analyses, reports, and briefings. There are many players, spectators, and decision-makers involved as a major program proceeds toward a DSARC milestone review. The relationship among the principal participants in the DSARC process is shown in Figure 2.

The project manager (PM) initiates the program review cycle within his system command, briefing the command's management and seeking approval to proceed to the next decision point—the Chief of Naval Material and the Acquisition Review Board (ARB).

The PM briefs the ARB on the status of the program including: technical performance, test results, schedules, alternatives, quantities, funding, and potential technical risks. His purpose is to demonstrate to the ARB and CNM that the program is ready to proceed into the next acquisition phase. The PM must address mission need, capability, and deficiency, as well as program definition, objectives, progress, technical risks and solutions, pertinent options, life-cycle costs and funding, business plans, support plans, and contractual strategies, as appropriate to the state of the program (DSARC 0, I, II, or III).

After the PM receives approval of the proposed program from the Chief of Naval Material (CNM), he briefs the CEB on the status of the program. The CEB may direct the PM to change the content of the briefing and accent issues relevant

FIGURE 2
Program Cost Review Cycle



to the efficient and timely acquisition of the weapon system. The PM, having incorporated into his briefing the changes directed by the CNM and CNO, will brief the Department of the Navy Systems Acquisition Review Council, on the status of the program. Approval to proceed to a DSARC milestone decision review must be obtained from DNSARC.

Before the DSARC review, the PM will present to the OSD Cost Analysis Improvement Group each program alternative under consideration and explain how the cost estimates were derived. Concurrently, the Resource Analysis Branch (Op-96D) presents the independent life-cycle-cost estimate to the CAIG, and a comparison of the PM's cost estimate and the independent cost estimate. The data base, methodology, and estimating relationships used to generate the cost estimates are discussed with the CAIG members.

The PM, during the program review, will present to the DSARC principals all the issues, problems, alternatives, and funding that were presented to the DNSARC. The PM must obtain approval from the DSARC principals to proceed with the acquisition of the weapons system, i.e., to another milestone.

Role of Op-96D in the Program Review Cycle

The Resource Analysis Branch (Op-96D) analysts are generating an independent life-cycle-cost estimate at about the same time the PM is generating his program cost estimate and preparing to brief the program status at the system command level. The ground rules and assumptions used by the PM to generate his cost estimate must also be used by the Op-96D cost analysts. The description of the program for cost-estimating purposes must be the same for all cost estimators; for example, performance characteristics, design features, quantities, schedules, and escalation/inflation indices should be identical to generate comparable cost estimates.

The cost-estimating approach and methodology to generate program cost estimates by the PM and Op-96D analysts are often different. The PM may generate his cost estimates using engineering (bottom-up) methods, and Op-96D analysts generate their cost estimates using statistical/parametric (top-down) methods. When the program is approaching a DSARC II or III decision, Op-96D analysts frequently visit the prime contractor (and sometimes major subcontractors) to discuss development/production aspects of the program, obtain actual cost data on prior phases, and discuss the contractor's cost projections. All of these trips are coordinated with the PM. As the program goes through the review cycle, the PM's staff and Op-96D cost analysts carry on a continuous dialogue on how the respective (PM's and independent) cost estimates were derived, that is, data base used, learning/experiences curve assumptions, competition, and anything that may have a significant impact on program acquisition cost.

Before the CEB program review, pre-briefs by the project manager and/or Op-96 action officers take place within the Navy Program Planning Directorate (Op-090), to acquaint the OPNAV managers with the details of the program and any potentially controversial issues. The OPNAV review cycle starts with a briefing to the Director, Systems Analysis Division (Op-96), and Director, General Planning and Programming Division (Op-90), by the Op-96 action officer. The Op-96 action officer function is to provide an objective analysis and recommendations to Op-96, Op-90, and Op-090 concerning need for the system, pros and cons of the program, alternatives, program structure, and cost and manning implications. A CEB preview brief is held to ensure that the project manager is ready to proceed to the scheduled CEB.

Several days before the CEB preview, Op-96D analysts prepare an Op-96D assessment which is incorporated into the Op-96 assessment for the CEB preview chairperson (Op-90). The Op-96D assessment addresses all financial aspects

which are potential issues (e.g., funding shortfalls, pros and cons of different alternatives), and usually gives a comparison of the preliminary Op-96D cost estimate and the PM estimate. The Op-96D assessment is provided to the PM and the cost comparison is incorporated into the PM's briefing.

On the day of the CEB preview, the Op-96 action officer and the Op-96D analysts pre-brief Op-96 and Op-90 before attending the CEB preview. The CEB preview chairperson frequently directs that changes be made to the briefing, such as addition or deletion of procurement alternatives, schedule changes, and consideration of different procurement strategies. Some changes may require revisions to the PM and Op-96D cost estimates.

Op-96D's preparation for the CEB is similar to that for the CEB preview. The Op-96D independent cost estimate is revised/refined and the assessment is provided to the Chief of Naval Operations, and to the PM for incorporation into his briefing. On the day of the CEB, the Op-96 action officer and Op-96D analysts pre-brief Op-96, Op-90, Director of Program Planning, and Op-090, Director of Navy Program Planning. It should be noted that the PM knows what the independent cost estimate is before the CEB because of the continuous dialogue between both staffs. The PM and Op-96D cost estimates are presented at a high level of aggregation (RDT&E, investment, operating and support), and at the major subsystem level for the acquisition phase and the first-level element structure for operating and support phase. Any differences in cost estimates at the aggregate or element level are highlighted for management, such as initial spares and average unit flyaway cost.

About 3 days before the DNSARC, Op-96D (in his SECNAV Advisor role) briefs the ASN(FM) on the technical, programmatic, and financial aspects of the program, and on the independent cost estimate and assessment. The ASN(FM) is generally interested in such issues as shortfalls in program funding in the next 2–3 fiscal years, cost growth since start of the program, type of contract award, and reasons for significant differences in PM and Op-96D cost estimates.

Two days before DNSARC, Op-96D analysts prepare an assessment to the CNO, PM, and the DNSARC principals, incorporating any changes necessitated by CEB directions. The PM's and Op-96D program cost estimates are presented to the SECNAV (DNSARC), identifying any major differences in the cost estimates for various elements in the RDT&E, investment, and operating and support phases of the program. The project manager will usually present the program cost estimate and the independent cost estimate, at the aggregate level, to the DNSARC members. Op-96D analysts usually attend the DNSARC.

Op-96D is required to present the independent cost analysis/estimate to the OSD Cost Analysis Improvement Group 15 days before the DSARC review date. Until October 1980, Op-96D presented brief technical and programmatic descriptions of the program, the independent cost estimating methodology, the independent estimate, and the Op-96D assessment of the PM's estimate. The PM

attended the CAIG briefing, primarily to answer technical/programmatic questions that might arise. Then in October 1980, the CAIG issued new guidelines as to what must be addressed at the CAIG briefing. Op-96D's function was essentially the same as before but, for the first time, the PM was required to brief his cost estimate and methodology. Since that time, Op-96D has coordinated the division of briefing topics with the PM. In practice, the PM has usually presented a condensed version of his DNSARC briefing, along with his cost estimate and methodology. The Op-96D presentation is the same as before except that minimal technical descriptions are included.

The OSD CAIG acts as the principal advisory body of the DSARC on matters related to cost. The CAIG provides DSARC members with a review and evaluation of independent and project manager cost estimates prepared by the services for presentation to each DSARC. These cost reviews consider all elements of system life-cycle costs, including research and development, investment, and operating and support. (See DOD Directive 5000.4, OSD Cost Analysis Improvement Group [CAIG], October 30, 1980, for a list of responsibilities.)

After the CAIG briefing, CAIG analysts conduct a detailed review of Op-96D and PM cost estimates and methodologies. This may start several days before the CAIG briefing. The CAIG analysts are interested primarily in the data base and techniques used in developing the methodologies, and the ground rules and assumptions used in the application of these methodologies. The CAIG analysts then prepare an assessment of the PM and the Op-96D cost estimates, and frequently develop a CAIG independent estimate.

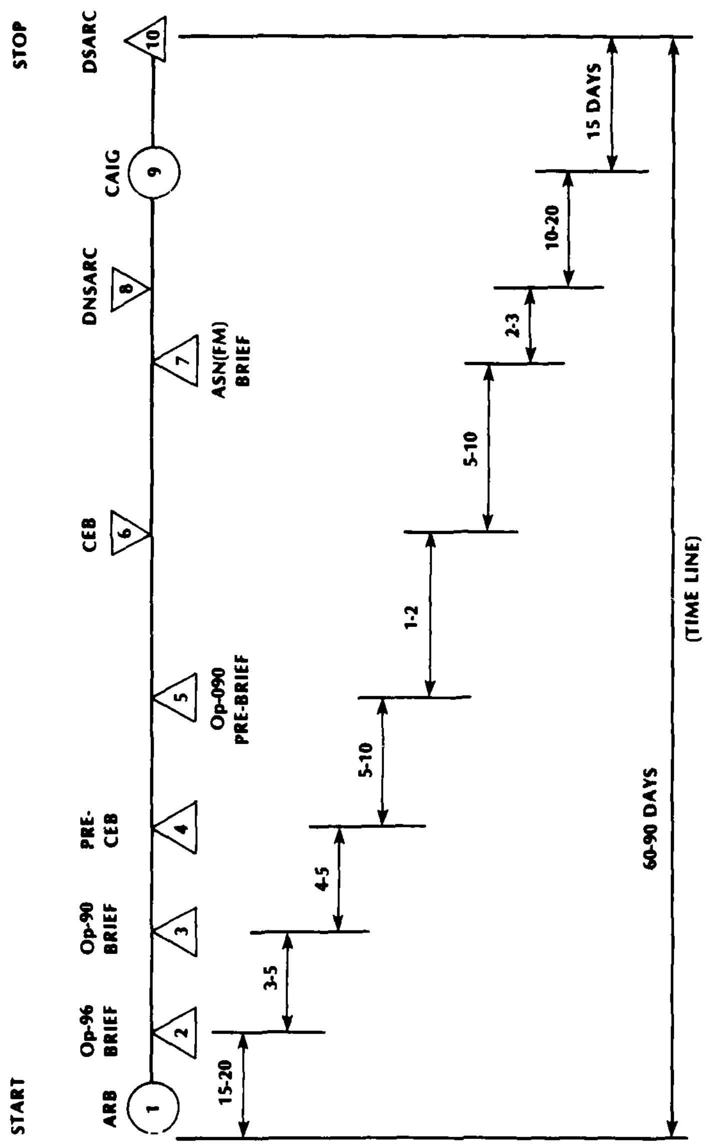
The CAIG assessment/independent estimate is incorporated into a memorandum to the DSARC principals from the CAIG chairperson. The CAIG chairperson presents an assessment/estimate at the DSARC meeting. The PM's and the Op-96D cost estimates are presented to the DSARC principals by the project manager. Op-96D analysts do not attend the DSARC.

The program review cycle from the start of the Acquisition Review Board review and Op-96 pre-brief to its conclusion with the DSARC milestone review is shown in Figure 3. There are 10 briefing points in the Navy program review cycle for the project manager and the Op-96D analysts to consider, and it takes approximately 60–90 days to cover all the briefing points.

Elements of Program Review By Op-96D

When Op-96D cost analysts prepare an independent cost estimate for a program, they are obligated to review the total program the project manager presents to the CNO/SECNAV for a decision. The purpose of the review is to confirm that the program conforms to all applicable Department of Defense directives and instructions, design-to-cost, life-cycle-cost, and CAIG guidelines. Quantities, schedules, funding profiles, and appropriations must be reasonable and consistent within the acquisition and operating phases of the program. Infla-

FIGURE 3
Program Review Briefing Cycle



tion/escalation and cost-estimating methodology must be correctly applied to estimate total program cost.

The Op-96D program review will usually cover, but is not limited to, the following items as each program proceeds through the acquisition review cycle:

—The inflation indexes and outlay rates used by the PM in generating current-dollar costs.

—*The cost-estimating methodology used by the PM in calculating flyaway unit* cost and life-cycle cost.

—The funding profiles, quantity buys (by year, totals) outlined for the program.

—The quantity of training rounds, initial spares requirements for the program.

—The development plan, test program, and production schedule for feasibility and conformity to DOD regulations.

—The appropriations included in the program cost estimate.

—Adherence to OPNAV instructions on standards of presentation.

—*Consideration as required, of the impact of competition in the program cost* estimate, and estimate of savings due to competition.

—Consistency of the program cost estimate with the amounts shown in the FYDP program page.

—Comparable and consistent analysis of alternative concepts for a program in terms of cost, schedule, and quantities (all resource requirements).

—The business base of potential contractors, along with the cost/availability of materials, and the impact of labor costs and future labor rates on a program cost estimate.

Summary of Op-96D Functions

The functions of the Resource Analysis Branch can be summarized as follows:

WHAT WE DO

—Prepare independent weapon system life-cycle-cost estimates;

—Assess system command cost estimates;

—Develop cost analysis methods;

—Represent the Department of the Navy at CAIG briefings and coordinate Navy and CAIG actions.

HOW WE DO IT

—Collect cost/performance/design data on weapon systems;

—Develop cost estimating relationships for systems and subsystems;

—Develop cost methodology;

—Develop weapon system cost models;

—Computerize cost models;

—Calculate weapon system life-cycle-cost estimates.

WHEN WE DO IT
—Systems in acquisition process (CEB/DNSARC/DSARC);
—Systems in special review.
FOR WHOM WE DO IT
—CNO and ASN(FM);
—DNSARC principals;
—OSD CAIG.
WHY WE DO IT
—To provide an independent (non-proponent) weapon system cost estimate/assessment;
—To assist managers in decision-making.

In summary, the role of SECNAV/CNO Advisor for Resource Analysis and his staff (Op-96D) is to be a consultant to the project manager, Office of the Chief of Naval Operations, and the Office of the Secretary of the Navy on cost/resource issues as the weapon system proceeds through the acquisition review cycle.

139 The Multicountry, Multiperiod Payments Problem

Dr. David Blond
Robin L. Meigel

The multicountry and multiperiod payments problem is unique to the North Atlantic Treaty Organization (NATO) E-3A program. It may, however, be the model for future cooperative development and procurement within NATO. The present structure for ensuring equitable payment for costs for the NATO E-3A program is unfair to most of the nations participating. Germany has been particularly vocal about the inherent inequity in the approach adopted by the NATO airborne warning and control system (AWACS) Program Management Agency's Legal and Contracts Committee.

The Problem

The problem is quite simple. Taking the NATO E-3A program as a case in point, we see that initially each nation agrees to fund its share of the procurement costs, using a fixed, constant-dollar share as its base for budget calculations. After the fixed share is agreed to, in this case 42 percent for the United States, 30 percent for Germany, the next step is to cost out the program in base-year currency (in the case of the NATO program, the base year is 1977 and the currency is the U.S. dollar). Of course, the funding is not needed all at once, so there is a yearly flow of resources decided upon in consultation with the prime contractor. For the E-3A program, the amount needed varies over the 6 years of the procurement phase of the program. Each state must also agree to the full costs in then-year, or inflated, dollars. Thus, there is an open-ended commitment that cannot be measured in advance.

The most straightforward method of handling the joint-funding problem is to ask each state to make up its share of the costs in the year they are incurred. Thus, if $200 million were owed in the first year, then the United States would pay $82 million, the Germans $60 million, and so on.

There are 13 nations in the E-3A program, and not all can pay the full amount owed in the year due. Inflation is a variable whose impact is unknown; but, more importantly, most nations do not have excess budget authority available to pay E-3A costs until later in the program. Some nations can pay their shares in the final 2 years; some in the middle 3 years; and some, like the United States, whenever needed. There is, therefore, a mix of different patterns of payment that

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must be rectified with the need to maintain a balance of shared contributions to the cost of procurement.

The program can go forward so long as we can devise a payments package that preserves at least the semblance of the original fixed-dollar shares. While the United States may pay 90 percent in the first year and 50 percent in the second year, it may also only have to pay 20 percent in the third year and 20 percent in the fourth year, and pay nothing at all in the last two periods. The cumulative sum of the total program expenditure weights, measured in constant dollars, times the yearly share to be paid; i.e., 90 percent, 50 percent, 20 percent, 20 percent, 0 percent and 0 percent, divided by the total program cost in constant dollars, yields the original program share itself.

By applying constant-dollar weights to the current-dollar expenses, it leaves it to a toss-of-the-coin situtation to decide if the final payment arrangement is equitable for all. This is essentially what the United States and the 11 other countries have decided to do. Germany, however, balks at this "simplistic" approach, and with good reason—it is inherently unfair, and there is a far better way to handle the problem.[1]

Letting It Be Decided by Chance

The toss-of-the-coin method is the simplest to implement. It means, essentially, that if Germany's share of the constant dollar costs in 1983 is 70 percent, then it must also pay 70 percent of the current-dollar costs incurred in that year. The unfairness here is that 70 percent of the current-dollar costs may be far greater than 90 percent of the costs the year before, even assuming the constant-dollar costs are exactly the same for both periods (if inflation were greater in 1983 than in 1982, this could be true).

How can rational states justify this inequity? One justification is that there is an inherent time value of money that must be taken into consideration when judging the fairness of a payment method. By putting money in early, the United States incurs a loss in procurement, or even additional financing charges (as the U.S. Federal Government deficit must be financed). This loss is compensated by the gain derived from paying less, in terms of current dollars, later in the program. There is, however, a better way to handle the problem; it is essential that the alternative method, and not the current AWACS payment approach, serve as the role model for future collaboration programs.

An Alternative: the Funds-Transfer Method

A more rational approach to the problem of AWACS cost sharing, one that conforms with our requirement that the obligations of the participants be

1. The German's recent note, "Cost Sharing, Funds and Exchange Rate Problems in Collaborative Projects" (Annex II to Addendum to AC/94-WP/66), is a case in point. They recognize the need to create a more rational method for sharing program costs on such multinational programs.

measured in real-dollar terms, and that those who fund the early stages be compensated by the late payers for the time value of money, is the "funds-transfer" approach. It preserves the negotiated program shares as a basic working principle while allowing the schedule of individual dollar payments to change. The fixed-share obligation in real terms remains the ultimate focus for deciding that each state's contribution is equitable.[2]

There is a difference between cost escalation due to program changes, and increases due to inflation alone. The bottom line is that the invoices will have to be paid whether cost increases are due to program change orders, or to general inflation. The burden of paying these unanticipated costs should not fall disproportionately on the late payers, since it is unclear who is responsible for such unanticipated program change costs. Further, these costs are not easily separated from those associated with overall inflation.

There is potential for serious conflict over the interpretation of the meaning of "1977 dollars" as stated repeatedly in the multilateral memorandum of understanding. The terminology "1977 base dollar" assumes that this is a measure of value. As such, we should be able to apply a discount rate to reflect the opportunity cost to the government. Opportunity cost is not related to the inflation rate on the E-3A procurement itself. A good proxy for this implied cost is the U.S. Government's borrowing costs as reflected in the treasury bill rate. A case can thus be made for applying this rate for other participants in a U.S. dollar-based program, such as AWACS, because the U.S. dollar reserves of foreign governments are usually invested in these government securities. It is, therefore, the logical discount rate to be used when determining 1977-dollar equivalents for inflated program costs.

Finally, the opportunity cost or time value of money argument applies only to dollars that the early paying states fund *in excess* of their negotiated program shares. The United States can legitimately insist on compensation only for the marginal payments made over its agreed share of the constant-dollar costs (42.1 percent). When the staggered-payment schedules are looked at in this way, we can readily interpret that any fundings in excess of the 42.1 percent limit are, in reality, loans to cover underpayment by other participants. This marginal approach results in a method which, when the actual cash outlays are discounted over time, yields an allocation of the program cost burden according to the fixed shares agreed upon in the original agreement.

How the Funds-Transfer System Works

The fixed share of the basic program schedule in 1977 dollars is affirmed. The staggered fixed-dollar payment schedule is accepted as a valid approach. Under

2. This is the same principle as buying a car either for credit or for cash. Each person is paying the same base price but, depending upon the term and rate charged for the loan, the final cost to each car buyer differs.

the funds-transfer method, each country pays its yearly share as determined by the second, staggered-payments schedule. For example, if Germany is responsible for 60 percent of the fixed-dollar costs in 1983, it must pay 60 percent of the current-dollar costs in that year.

The difference between the actual amount paid in a given year and a country's negotiated fixed share is then tracked with each quarterly payment. Using the above example, the difference between Germany's 60 percent funding and its constant-dollar share of only 30 percent is viewed as a loan to nations paying less than their fixed share in that year. An interest-like surcharge accrual is calculated as a bookkeeping entry to the credit of the countries funding the excess. Conversely, a charge at the same rate is applied to nations paying less than their fixed shares in the given period. The actual rate used should, in any event, equal the discount rate agreed upon by the member nations as appropriate for valuing 1977 dollars.

Cash outlays associated with the surcharge balances are not made until the program is completed. These surcharges are compounded on the outstanding balance, including earlier accumulated surcharge calculations and credits. Overpayments are netted against balances as they occur.

To the extent that a country cannot make its full current-dollar payments as scheduled, it may borrow additional funds from other participants.

After the procurement phase is completed, a final accounting of the principal and surcharge balances is made. By definition, the *debit* balances of the net borrowers equals the *credit* balances of the net creditors so that a simultaneous transfer of funds can, in effect, net these bookkeeping records at the close of the program.

A Hypothetical Example Using NATO E-3A

To see how the new system works, a hypotheti(:ample using inflation rates that are somewhat above the current rates forecast is presented (in Table I). United States Treasury bill rates are used to value the under- and overpayments by member states. These rates are consistent with the underlying rate of future U.S. inflation.

United States government payments, using the current system, are estimated to equal $1.3 billion, or about 37 percent of the program cost. Thus, the United States achieves savings equal to the difference between its fixed, 42.1 percent share, and its actual current-dollar contribution. The line "variable % less 42.1 %" represents the amount of under- or overpayment for each year, based on the original fixed-dollar share of each state, in this case the original baseline fixed-dollar share. The next line, "Surcharge @ T-bill rate," shows the net interest earned or paid out on the accumulated balances. As each yearly overpayment accumulates, principal plus interest, there is a credit available in the U.S. account

TABLE I
A Hypothetical Example

AWACS FUNDS TRANSFER PROPOSAL: A New Method of Allocating Escalated Program Costs

Equitably A Hypothetical Example Showing 3 of the 13 Nations Participating

	Prior 1978	78	79	80	81	82	83	84	85	Total	Present Method (Current $)	Program Shares Funds Transf Method (Current $)	Fixed Share per MMOU
AWACS Current $ Forecast:	16.4	20.1	221.0	478.5	721.3	672.8	575.4	446.0	319.1	$3470.5			
Underlying Program Cost Inflation (% pa)		9.5	10.1	20.0	20.0	15.0	15.0	15.0	10.0				
9-12 mo. Treasury Bill rate (% pa)	6.1	8.3	10.7	10.4	8.8	10.0	10.1	9.6	9.6				
United States ($ millions)											36.5%	39.4%	42.1%
Variable % Payments:	8.5	10.2	126.0	306.2	451.5	276.5	87.5	.5	.3	$1267.1			
Variable % less 42.1%:	1.6	1.7	33.0	104.8	147.8	(6.7)	(154.7)	(187.4)	(134.0)				
Surcharge @ T-bill rate:	.1	.3	3.9	15.1	27.0	32.9	20.8	3.8	(8.7)				
End-of-year balance:	1.7	3.7	40.6	160.5	335.3	361.5	227.6	44.0	(98.6)	---Paid out in 1986			
Federal Republic of Germany ($ millions)											33.2%	31.7%	30.7%
Variable % Payments:	4.5	6.6	54.4	79.9	113.2	230.1	361.6	281.0	20.4	$1151.7			
Variable % less 30.7%	(.5)	.4	(13.4)	(67.0)	(108.2)	23.6	185.0	144.1	(77.6)				
Surcharge @ T-Bill rate:	(.03)	(0.1)	(1.5)	(8.5)	(17.4)	(19.3)	(2.7)	10.9	4.6				
End-of-year balance:	(.5)	(.2)	(15.1)	(90.6)	(216.2)	(211.9)	(29.6)	125.5	52.2	- - Received in 1986			
Italy ($ millions)											7.8%	6.9%	5.6%
Variable % Payments:	0.0	0.0	0.0	0.0	9.7	29.2	11.5	39.8	181.2	$271.4			
Variable % less 5.6%:	(.9)	(1.1)	(12.4)	(26.8)	(30.7)	(8.5)	(20.7)	14.8	163.3				
Surcharge @ T-Bill rate:	(.06)	(.2)	(1.6)	(4.5)	(6.9)	(9.4)	(12.4)	(11.6)	2.9				
End-of-year balance:	(1.0)	(2.3)	(16.2)	(47.5)	(85.0)	(102.8)	(136.0)	(132.8)	33.5	- - Received in 1986			

Numbers in parentheses represent underpayments or outstanding debit balances.

until 1985. The total required payback is described in the last column in the series "End-of-Year Balance." In the U.S. case, its credit of $44 million in 1984 becomes a debit of $98.6 million in 1985, as the last U.S. payment is far below the program costs paid out in that year by late paying states. The United States, in effect, owes this amount to the other countries.

This method is fair to all nations and should be acceptable when it is time for late payers to fund their agreed contributions. Italy, a late payer, originally contracted for a 5.6 percent share of the program. If the toss-of-the-coin approach were followed, Italy would ultimately pay 7.8 percent of total program costs. By applying the funds-transfer method, Italy's share of total costs would decline to just 6.9 percent.

Similarly, Germany pays just 1 percent more for its present payment pattern, rather than 2.5 percent more as would be required if the U.S. method is applied. The United States still saves money while being fully compensated, correctly this time, for its early payments. The U.S. share now becomes 39.4 percent of the total estimated program. This is still 2.7 percent less than the United States' original, fixed-dollar share, of 42.1 percent.

Conclusion

The funds-transfer method is a pragmatic and equitable solution to the problem posed by multilaterally funded defense programs when payment phasing differs from fixed yearly shares. It is a generalized approach and can therefore serve as a precedent for future cooperative projects. The funds-transfer method's advantages are that it is equitable and readily implemented, it is indifferent to cost growth due to inflation or program changes, and it can easily accommodate stretched-out payment schedules or alterations in individual state contributions without undue burden placed on the early-paying states.

This new approach should be acceptable to Germany as well as to other nations. In the Tornado project, a joint German-British-Italian effort to develop a multirole fighting aircraft, Germany is advocating a final, monetary compensation between participants to settle residual differences in work-shares vs. purchase-shares. It is logical that Germany may accept a side calculation of the opportunity benefits and costs accruing to the early vs. the late payers in the NATO AWACS program, so long as the final netting out takes place after all actual expenditures have been made.

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Selecting Estimating Techniques Using Historical Simulation

Charles A. Graver

The development of cost estimates is a critical part of the cost-benefit comparison of alternative government programs. The specific cost estimates will often be the deciding factor among alternatives, and can be the death blow to an entire program if none of the alternatives is affordable.

But what cost-estimating techniques should be used? There are two classes of commonly used estimating techniques that are appropriate for the early phases of the development life cycle when system performance characteristics are being selected and detailed hardware component specifications have not been made. These are (1) costing by analogy, in which the costs of similar systems are used for the estimate; and (2) cost-estimating relationships (CERs), which are equations relating cost to system performance characteristics. The former is dependent on the availability of analogies, and the estimates derived are interpolations from the existing data. CERs, on the other hand, can be used for interpolations as well as extrapolation. The latter is most often the cost analyst's problem.

Within the class of the cost estimating relationships, there are still a number of choices to be made. What performance characteristics drive the cost and what is the functional relationship?

The usual selection procedure is to first identify the physical and performance characteristics (independent variables) that are likely to be cost-driving variables. Next, data on cost and these variables are collected for previously built systems. Then a number of functional forms relating cost and some or all of the performance characteristics are tried. Least-square curve-fitting techniques are the usual tools, and these are applied after the functional form has been transformed into a linear equation. Statistics derived from the regression analyses of the least-squares fit are then typically used to select the most significant variables and best functional form. The index of determination (or R^2) is commonly used, with the best equation having the R^2 closest to 1. Computer programs, such as six curve or stepwise multiple regression, have been devised so that a specified range of variables and functions can be processed quickly.

Problems in Selecting Estimating Techniques

A number of theoretical and practical problems arise from this method of picking the estimating technique. They are often not understood, and can result in serious mistakes. They will be familiar problems to the seasoned analyst.

The first problem is the *definition of accuracy.* Naturally, error minimization is the goal. But what type of error? Is the analyst interested in minimizing ab-

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solute errors or proportional errors? Least-squares curve-fitting techniques do both, depending on the functional form used. For example, the least-square fit of linear equations minimizes absolute error. On the other hand, equations of the form $y = ax^b$ usually have the least-squares fit applied after taking logarithms of both sides of the equation. This is equivalent to minimizing the proportional error. Thus, different concerns about accuracy are used, often without the analyst's being aware of them.

The second problem is *comparability of selection criteria.* When a number of functional forms are possible, which is best? Table I illustrates the problem. Here six curves are being evaluated. The criterion used for the comparison is the index of determination (or R^2), and the closer to 1, the better the relationship. Curve 6 is therefore the best. However, an examination of the residuals quickly shows that there are serious problems with this estimating relationship. The error for the large values of X is so bad that negative costs are predicted.

The problem is that the indexes of determination are not comparable. This is because the index is calculated on a least-squares fit. But the fit is not applied until the candidate curve has been transformed into a linear form. For example, the linear form of equation 6 (Table I) is

$$1/Y = A + (B/X)$$

The fit criterion is then

$$\sum_{i=1}^{n} [(1/Y_i) - A - (B/X_i)]^2$$

and A and B are picked to minimize this quantity. The index of determination is calculated from this fit, and hence applies to how well $1/Y$ is predicted, and *not* to the quantity of interest Y. Hence, the values of the indexes are not comparable.

This brings up the third problem. What is the *interpretation of the usual statistics* which accompany regressions? Clearly the R^2s are not comparable. But what does the standard error of the estimate mean, and how does one interpret the other statistics? In fact, the statistical assumptions of the models are rarely stated explicitly, and the analyst rarely checks to see that his data fit the model. Linear regression assumes an additive error term that is normally distributed around the true linear relationship with a variance which is statistically independent of the value of the input variables. The model form $y = ax^b$ assumes a multiplicative error term with a log normal distribution and a variance that increases with increasing input variable values. Without checking these assumptions, the interpretation of the output statistics is questionable. Yet F-tests and

TABLE I
Model Comparisons

X MEAN: 7.5 Y MEAN: 114.79

NUMBER	CURVE	INDEX	A	B
1	Y = A+B*X	.870942	1.57802	15.0134
2	Y = A*EXP(B*X)	.734369	12.9491	.238688
3	Y = A*X+B	.943895	5.5841	1.46224
4	Y = A+(B/X)	.644278	164.108	-214.977
5	Y = 1/(A+B*X)	.45971	.093564	-8.48198 $-3
6	Y = X/(A*X+B)	.982073	-1.79869 $-2	.206394

For which curve are details desired (number) ? 6

COEFFICIENTS:

	EXPECTED VALUE	95PCT CONFIDENCE LIMITS	
A:	-1.79869 $-2	-2.38852 $-2	-1.20886 $-2
B:	.206394	.188814	.223974

X-ACTUAL	Y-ACTUAL	Y-ESTIM	95PCT CONFIDENCE LIMITS	
1	5.2	5.30765	4.93682	5.73871
2	11	11.7357	10.9222	12.6801
3	23.2	19.6807	18.0428	21.6457
4	44.1	29.7516	26.3993	34.079
5	76.4	42.9333	36.25	52.638
6	116.4	60.9304	48.0256	83.3188
7	141.3	86.9715	62.3615	143.668
8	159.2	128.002	80.2055	316.774
9	164.6	202.191	103.034	5372.98
10	167.8	376.996	133.284	-455.022
11	169	1288.27	175.282	-240.812
12	170.4	-1270.07	237.532	-172.871
13	173.8	-473.845	339.343	-139.516
14	176.1	-308.221	536.01	-119.696

T-tests are still made, and, along with R^2s, are used to justify selection of variables and functional forms.

The problem of interpretation has been compounded by the use of stepwise regression techniques to select the model. Prior to the introduction of the stepwise regression technique, candidate CERs had to be hypothesized, with the hypotheses presum: y based on engineering rationales or some other criteria. The need for this ,ecification was *operationally* removed when the stepwise multiple regression routine became available. Only the candidate variables and their allowable transformations had to be specified. However, when the stepwise routine was applied, the resulting CER, while fitting the data well, often had no physical rationale. The applicability of the result then became questionable, even with good fit. For example, suppose a hundred different CERs, differing in form or variable selection, are tried. It is not surprising that one or two will fit well enough to be judged significant at the 0.05 significance level. This follows from the fact that the CER hypothesis is not picked *a priori*, but is the result of finding the one that fits the data best from a hundred different candidate CERs. As such, this fit could easily represent one of the five times out of 100 that such a fit theoretically occurs by chance (at the 0.05 significance level).

This discussion throws into doubt one of the central assumptions of least-squares curve-fitting—that which fits the past best will predict the future best. For it is this criterion that the stepwise regression procedure uses to choose CERs. Furthermore, when functional forms are different, the criterion is not applied in a comparable way (Problem 2). As a result, a fourth problem arises—*Is the best-fit selection criterion best?*

The fifth problem is plagued by this question. How does the analyst state the estimating relationship's *capability to make extrapolations?* Predicting the cost of procurements that represent extrapolations from the data base is the problem that the cost analyst usually faces. It seems we are always required to estimate the cost of a bigger or faster plane, or one that is *better* in some combination of characteristics than those procured in the past. While using the criterion of "that which fits best, predicts best" should work reasonably well for cost predictions that are interpolations on the characteristics present in the data base, the criterion yields little information concerning cost predictions of procurements which represent extrapolations from the characteristics in the data base. Theoretically, one should calculate prediction intervals, but these are so wide for most extrapolations that they become meaningless. Thus, a means for estimating the accuracy of techniques to make extrapolations is required.

The final problem is how to *compare a wider class of estimating techniques.* The discussion to this point has dealt with techniques which use the entire data base. But this excludes costing by analogy and other methods which systematically use a subset of the data. For example, make a linear relationship using all data with characteristics no more than 20 percent different from the procurement to be estimated. One cannot even calculate the usual statistics for these methods, let alone compare them in a fair manner.

Historical Simulation Scope

Historical simulation was developed by the author in 1969 to help the analyst address these problems.[1] It provides an independent view of the estimating technique selection process, because the focus is changed from fitting the data best to predicting best. As a result, historical simulation is a complementary tool which can be used along with the usual methods to select better estimating techniques.

The analyst is still required to define his accuracy concerns (absolute or proportional errors). However, this choice is made explicit and does not depend on the model form. The selection criterion is then applied in a comparable fashion across all candidate estimating techniques. This includes costing by analogy and other methods which cannot normally be compared to CERs.

Historical simulation provides summary measures of the candidate techniques' estimating value, which is easy to communicate and not obscured by questionable statistical jargon. In addition, statistically valid measures of the historical simulation results have been derived and can be used when the usual linear regression assumptions are warranted.

When the data is properly organized, historical simulation provides real insight into the ability of estimating techniques to make extrapolations. The measure depends on how well these extrapolations would have been made in the past. Thus it gives a more pragmatic measure than the usual statistical prediction intervals.

Estimating Procedures

A wider perspective of the estimating process is needed to set the stage for the historical simulation development. This is provided by viewing the problem as selecting a cost-estimating procedure instead of just a CER. The distinction between these two concepts is given below.

A cost-estimating procedure consists of an equation form (EF) plus a technique for estimating the values of the parameters (in the EF) from some sample. An example of an estimating procedure is:

Equation Form

$$Y = a + bX$$

where

Y = production cost of the item to be estimated

X = the weight of the item to be estimated

Technique

Least-squares curve fit

1. C. A. Graver, *Historical Simulation: A Procedure for the Evaluation of Estimating Techniques*, Volume I, "Procedure Development and Description," and Volume II, "Some Examples," General Research Corporation CR-0364-1, June 1969.

TABLE II
Cost Estimating Procedures

PROCEDURE NUMBER	EF	TECHNIQUE
1	$Y = a + bV$	Least-squares fit
2*	$Y = a + bV$	Line determined by the closest two data points in terms of V
3*	$Y = a + bX$	Same as above, except closest measured in terms of X
4	$Y = aX^b$	Least-squares fit on $\log Y = \log a + b \log X$

where

Y = production cost

X = weight

V = volume

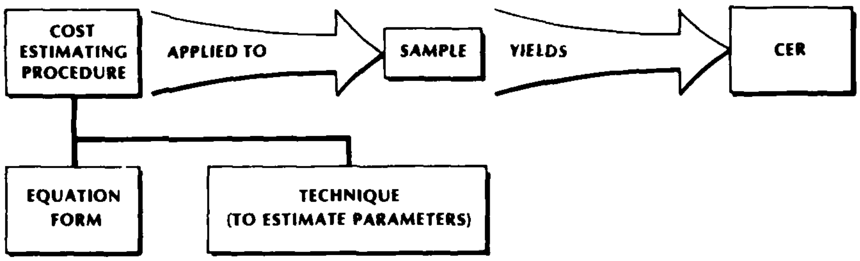
*Procedures 2 and 3 are very close to costing by analogy. In effect, the analyst assumes that if he forms a line with the two closest data points (in terms of his independent variable) to the point he wishes to predict, the estimate using this line will be better than an estimate made using a line that fits all the data.

A new estimating procedure results from choosing a new ER, a new technique, or both. Hence, the combinations given in Table II are all examples of alternative estimating procedures.

When a cost-estimating procedure, with EF $Y = a + bX$, say, is used in conjunction with a particular sample (i.e., a particular set of observations), there is derived an explicit cost-estimating relationship (CER); for example $Y = 10 + 25X$. This is a result of estimating the EF parameters by applying the parameter estimating technique to the given sample. Thus, every CER has identified with it a particular sample and an estimating procedure consisting of an EF and a technique. The relationship of these entities is pictured in Figure 1.

Historical simulation evaluates an estimating procedure by varying the sample to be used. This is described in the next section.

FIGURE 1
Relationship of CER and Cost Estimating Procedure



Historical Simulation Description

The job of a cost analyst is to try to predict the cost (in constant dollars) of a proposed future procurement. He has at his disposal a description of the proposed procurement in the form of a set of physical and performance characteristics. In addition, he has available physical and performance characteristics and cost data in constant dollars, for example, the 100th unit, on similar past procurements. Hence, his primary objective is the prediction of a future procurement using available historical data.

Historical simulation uses this primary objective in measuring the value of a cost-estimating procedure. This basic tenet can be stated as follows: The cost-estimating procedure which can best *simulate* predictions that would have been made *in the past will actually be best able to predict the future.*

To evaluate different cost-estimating procedures, using the tenet just stated, historical simulation calls for each candidate cost-estimating procedure to be tested on subsamples of the actual data base. For each subsample, the candidate cost-estimating procedure is used to predict the cost of procurements built after any of the procurements in the subsample.[2] These predictions are then compared to the actual costs.

To demonstrate this process, consider the following example comprising the 13 data points listed in Table III.[3] The data have been ordered as to date of first

2. This ordering of the data base [illegible] t a requirement. If the estimate to be made requires an extrapolation of a particular performance [illegible]acteristic, then the data should be ordered on the value of that performance characteristic.

3. N. R. Draper and H. Smith, *Applied Regression Analysis* (New York: John Wiley & Sons, Inc.), 1968.

TABLE III
Sample Data

PROCUREMENT NUMBER	FIRST DELIVERY	ACTUAL 100th UNIT COST	X_1	X_2
1	1960	95	1,996	153
2	1961	31	967	144
3	1963	60	2,414	149
4	1964	82	4,418	144
5	1966	25	852	107
6	1968	67	2,072	136
7	1970	243	10,408	177
8	1971	54	2,643	160
9	1972	112	3,786	172
10	1973	106	3,335	203
11	1974	183	6,374	196
12	1975	156	7,092	187
13	1977	177	10,304	167

delivery (second column), and the actual cost and the independent variables X_1 and X_2 have been collected for each data point: X_1 and X_2 are physical or performance characteristics (such as weight and speed) which should be useful in specifying the cost of the procurements to be estimated. The following cost-estimating procedure has been hypothesized:

$$(1)\quad \text{Cost} = a + b_1X_1 + b_2X2$$

where a, b_1 , and b_2 are to be estimated through the process of a least-squares curve.

A subsample of five items will first be used; that is, the first five rows of Table III are treated as the data base. This is the data base from which an analyst would have had to make cost predictions in 1967. Using a least-squares fit, the derived CER is

$$(2)\ \text{Cost} = -73.9 + 0.0104X_1 + 0.792X_2$$

From Table III, X_1 and X_2 for procurement number 6 are 2,072 and 136. If these values are substituted into the CER of equation 1, the predicted cost is 55.3. This represents a prediction because the sixth procurement is not in the subsample

TABLE IV
Predicted Costs Using First Five Procurements

PROCUREMENT NUMBER	ACTUAL UNIT COST	PREDICTED COST	RESIDUAL*
6	67	55.3	-11.7
7	243	174.4	-68.6
8	54	80.2	26.3
9	112	101.6	-10.4
10	106	121.5	15.5
11	183	147.5	-35.5
12	156	147.9	-8.1
13	177	165.4	-11.6

***Negative numbers are underestimates; positive numbers are overestimates.**

data base. From Table III the actual cost was 67; thus the cost is underestimated by 11.7.

Next, equation 1 can be used to predict the remaining data points 7-13. These predictions can be compared to the actual costs, and *residuals* calculated, yielding the results given in Table IV. As one can see, there were six underestimates and two overestimates.

The entire process described thus far is now repeated for a subsample size of six. That is, the sixth procurement is added to the subsample, taking the six top rows of Table III as the data base. This data base is the one from which a cost analyst would have made his cost prediction in 1969. Making a least-squares fit to this data base, the following CER is obtained:

$$\text{(3) Cost} = -68.4 + 0.0105X_1 + 0.76X_2$$

When comparing equation 3 with equation 2, it can be seen that the parameters have changed, although not by any great amount. This change is, of course, the result of adding procurement number 6 to the sample. The point to be remembered is that the explicit CER has changed, but the CER form, i.e., Cost $= a + b_1X_1 + b_2X_2$, and the parameter estimating technique, namely, least squares, has not changed. It is the cost-estimating procedure; i.e., the CER form and the parameter estimating technique, that is being evaluated by historical simulation and not any one explicit CER such as equation 3.

Predictions and residual calculations for procurements 7-13 can now be made using equation 3 yielding the results shown in Table V. Notice that procurement

TABLE V
Predicted Costs Using First Six Procurements

PROCUREMENT NUMBER	ACTUAL UNIT COST	PREDICTED COST	RESIDUAL
7	243	176.1	-66.9
8	54	81.7	27.7
9	112	102.8	-9.2
10	106	121.8	15.8
11	183	148.3	-34.7
12	156	149.0	-7.0
13	177	167.4	-9.6

TABLE VI
Predictions

SAMPLE SIZE USED	For Sample Point Number							
	6	7	8	9	10	11	12	13
5	55.3	174.4	80.2	101.6	121.5	147.5	147.9	165.4
6		176.1	81.7	102.8	121.8	148.3	149.0	167.4
7			85.4	114.3	128.1	177.4	183.9	227.0
8				102.1	103.9	161.5	172.6	229.3
9					110.7	166.3	176.1	229.2
10						164.5	174.9	229.8
11							179.7	223.7
12								227.1
13								

number 6 is not included since it was part of the data base used to derive equation 3.

The procedure described thus far can be repeated using subsample data base sizes of 7, 8, and on up to 13. In the last case the entire sample is used, and the usual least-squares fit is obtained. Of course, no predictions for which an actual cost exists in the data base can be made using the final CER. However, this is the CER which will be used to make the future prediction, if the estimating procedure being evaluated by historical simulation is chosen as the best method for predicting cost.

TABLE VII
Residuals

SAMPLE SIZE USED	For Sample Point Number 6	7	8	9	10	11	12	13
5	-11.7	-68.6	26.3	-10.4	15.5	-35.5	-8.1	-11.6
6		-66.9	27.7	-9.2	15.8	-34.7	-7.0	-9.6
7			31.4	2.3	22.1	-5.6	27.9	50.0
8				-9.9	-2.1	-21.5	16.6	52.3
9					4.7	-16.7	20.1	52.2
10						-18.5	18.9	52.8
11							23.7	56.7
12								50.1
13								

TABLE VIII
Estimated Parameters

SAMPLE SIZE	a	b_1	b_2
5	-73.9	0.0104	0.792
6	-68.4	0.0105	0.765
7	-74.6	0.0178	0.706
8	-31.8	0.0198	0.344
9	-45.2	0.0193	0.450
10	-38.6	0.0196	0.400
11	-50.2	0.0198	0.478
12	-44.6	0.0191	0.448
13	-63.9	0.0159	0.629

The outputs described can be conveniently summarized in a table of predictions (Table VI), a table of residuals (Table VII), and a table of parameter estimates (Table VIII). The interpretation of this output will be discussed later.

Generalization of the Procedure

In the reference cited in footnote 1, the above procedure is generalized, in terms of mathematical notation, which can then be applied to a wide range of estimating procedures, including analogy. Thus, the same evaluation procedure can be used to compare a wide class of estimating procedures.

Information on Extrapolation

In the example, the data were ordered in the time dimension; however, this need not always be the case. For example, the data set in Figure 2 has been ordered in the X-dimension, and the prediction problem represents a further extrapolation in the X-direction.

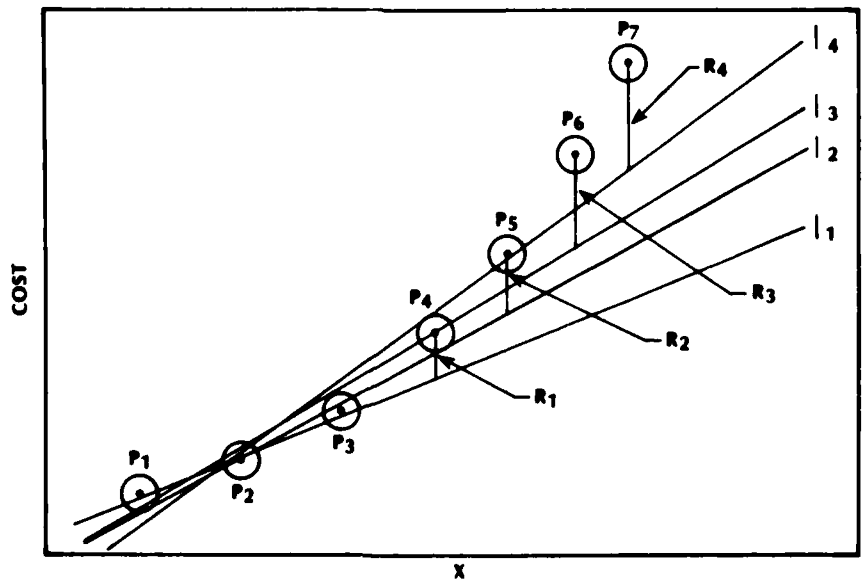
The candidate estimating procedure is

$$\text{Cost} = a + bX$$

and a least-squares curve-fitting technique is used to pick the parameters.

At the first stage of historical simulation, the first three data points (P_1, P_2, and P_3) are used to fit a line ℓ_1. The estimate of P_4 would be low by the amount R_1. At the next stage of historical simulation, line ℓ_2 would be derived using as the data base points P_1, P_2, P_3, and P_4. The estimate of P_5 derived from ℓ_2 would be low by R_2. The process is continued deriving lines ℓ_3 from data points P_1 through P_5, and ℓ_4 from P_1 through P_6. The estimates of P_6 (from ℓ_3) and P_7 (from ℓ_4) are low by R_3 and R_4, respectively. Thus, all the predictions obtained were low.

FIGURE 2
Theoretical Ex. nple



Looking at each of the lines, however, it does not seem that the fit (to the data they were derived from) is too bad. In fact, ℓ_4 would probably be accepted as a good model for the first six data points, using statistics based on regression theory.[4] Hence, the model would be accepted using the regression theory statistics, while it would be rejected using historical simulation.

Of course, in this case, a simple plot of the data would convince an analyst that he has the wrong model (it should be exponential rather than linear). This, however, is a consequence of a two-dimensional problem (cost and X) in which plots can be made and our illustration could be drawn. The analyst will not have the luxury of such plots when working with more than one independent variable, and an extension of this example to a multiple independent variable model can readily be made (without a figure, however).

Output Interpretation

In interpreting the results of historical simulation (or indeed, to make inferences from the usual regression statistics), the analyst is examining two basic questions about the cost-estimating procedure under study:

—Is the estimating procedure valid; i.e., is it a true representation of the cost generating process under study?

—How reliable is the estimating procedure; i.e., is the model variance, and hence the variance in the estimates, large or small?

The answers to these questions are used by the analyst to choose between different candidate cost-estimating procedures (ranking), to define new candidate cost-estimating procedures, and to make estimates about the prediction accuracy. Ways of using the historical simulation output for these purposes are discussed below.

Direct Examination of Historical Simulation Output

A direct examination of the contents of the output, Tables VI, VII, and VIII, can add insight into the question of model validity, the identification of questionable sample points, and the identification of new candidate estimating procedures. For example, the following inspections can be made:

1. Each column of Table VII gives the residuals for a particular sample point. One can ask if these residuals are improving (getting smaller in an absolute sense) as the sample size grows (that is, as the analyst looks down the column). One would expect the residuals to improve—or at least not get any worse—if the

4. It should be noted that there is another technique, called "time sequence plot of the residuals," which for the example being discussed would result in a sequencing of residuals from the usual regression analysis that would indicate a lack of fit. However, the consequences of retaining the model (in this example), i.e., the likelihood of underestimates, are more apparent when processed by historical simulation. Furthermore, even though residual plots should be analyzed whenever a least-squares-curve fit is made, the fact is that such examinations of residuals are often forgotten.

model is valid and the sample consistent. This behavior is not true for the test run sample. The residuals are erratic or tend to get worse for sample points 9, 11, 12, and 13.

2. Are there any consistent errors? For example, does the estimating procedure consistently underestimate (have negative residuals) most sample points? If so, then the cost-estimating procedure shows signs of bias. Again, by examining any column of Table VII, one might find sample points that are consistently under or overestimated by a substantial amount. In this case there is reason to suspect that the data point in question does not belong to the population, or that errors have been made in recording its cost or the values of the independent variables. For the test run data there appears to be no indication of bias, as the residuals are neither mostly negative or mostly positive. There are sample points, however, that show substantial consistent errors, such as points 7 and 13.

3. Residuals along any row of Table VII are all derived from the same subsample. Comparing two adjacent rows indicates the impact on the prediction process of the point added to the larger subsample. One might therefore ask if there have been significant changes, in some consistent manner, from one row to the next. If so, the sample point added is dominating the estimating procedure, and if the changes in residuals are not for the better (i.e., smaller absolute residuals), then the question of whether or not the sample point properly belongs to the population is again raised. As an example, if rows for subsample sizes of six and seven data points are compared in Table VII, we see substantial changes in the residuals. While some residuals have improved (sample points 9 and 11), others have definitely become worse (sample points 12 and 13). There is no question that sample point 7 has had a significant impact, but its impact is mixed.

4. Finally, the estimates of the parameters (Table VIII) can be examined. Are they reasonably stable, showing signs of convergence as the sample size grows? If so, then one feels a greater assurance of the model's validity; the information concerning the values of the model parameters is essentially the same from all the sample points. If not, then there might be something in the pattern of the estimated coefficients that would suggest a new candidate cost-estimating procedure or that would identify a questionable sample point. In Table VIII it can be seen that the desired stability did not take place for the test run data. The inclusion of sample points 7 and 8 had a significant impact on the parameter estimates. Hence, these points ought to be examined carefully.

In summary, there is a great deal of "look-see" evidence concerning the model validity in the output of historical simulation. This output can be used to build confidence in model validity, or, conversely, aid in hypothesizing a new cost-estimating procedure. In addition, it can help to identify questionable sample points. Furthermore, no information concerning the process has been lost.

Data Summarizations That Do Not Depend on Statistical Assumptions

Data summarizations (or statistics) discussed here have the property that they can be calculated and consistently interpreted for any candidate cost-estimating procedure. These summarizations can thus be used to compare all candidate estimating procedures.

This lack of dependence on statistical assumptions introduces uncertainty as to what data summarization is best. Hence, several different summarizations are suggested. Arguments for their use are necessarily heuristic in nature, and the choice of which particular summarization to use depends on the analyst's accuracy definition. He can exercise this choice by picking loss functions and weighting schemes best suited to his application.

Before describing the summarizations, it will be useful to identify the portion of the historical simulation output that will be used. Only the values from the residual table (VIII) are used, as it is the errors of prediction that are of interest. Which of these residuals to use is not entirely clear.

Using all of the residuals is appealing in that no information will be thrown away. However, there are problems involved in knowing how to use all of them fairly. The residuals are certainly not independent; hence, use of all the residuals introduces problems of statistical interpretation and weighting.

If, however, only one residual is used for each sample point, in particular the one made from the largest available subsample size—the entry in the diagonal of Table VII—then the problems of weighting and statistical interpretation are greatly reduced. Furthermore, this selection is not without heuristic justification. In effect, we are looking at the prediction made from the largest available subsample size for each procurement. These are the subsamples that would have been used and predictions that would have been made if the cost-estimating procedure had been used in the past.

For notational convenience, let us relabel these residuals by

$$R_{n_o+1}, \ldots, R_n, \ldots, R_N$$

where n_o was the minimum sample size used in the historical simulation and N is the size of the entire data base. The collection of these residuals will be referred to as $\vec{R}$.

The question being addressed in this section, then, is how to summarize the data in $\vec{R}$ so that one can choose between several estimating procedures. In addition, it will be useful if these summarizations indicate how well the estimating procedure will do in the future.

One such summarization is that of *average proportional error*. It is calculated as follows:

$$\text{(4)}\quad \text{Average Proportional Error} = \frac{1}{N - n_o} \sum_{i=n_o+1}^{N} \frac{|R_i|}{y_i}$$

where

y_i = actual cost of the procurement indexed by i
n_o = minimum sample size used in the historical simulation
N = the size of the data base

The average proportional error should be used when one is worried about *proportional* rather than *absolute* cost errors. In addition, this measure is probably the easiest to communicate. Every cost analyst has been asked to indicate how reliable his prediction is; for example, is it within ±20 percent? Having calculated the average proportional error, he can answer this query by saying, "The cost estimating procedure from which this estimate has been derived has an average proportional error of, say, 15 percent, which implies that if it had been used to make these types of predictions in the past, it would have been off on the average of 15 percent." Hence, a reasonable answer to the query would be that an error of ±15 percent should be expected.

Contrast the above answer to one made from the usual regression theory output utilizing statements of F-tests, T-tests, R^2, prediction intervals, etc. How aware of the underlying statistical assumptions or the meaning of these statistics is the recipient of the prediction results? Their meaning is certainly not as easy to understand as the average proportional error.

One drawback to average proportional error is that it places the same emphasis on predictions made from a sample of size 5 as predictions made from a sample of size 12. For any cost-estimating procedure that makes use of every data point in its subsample, this equality of weighting may seem unjustified. After all, predictions should be getting better as the sample size increases. Hence, the following weighted average proportional error is suggested:

$$\text{(5)}\quad \text{Weighted Average Proportional Error} = \sum_{i=n_o+1}^{N} \frac{W_i\,|R_i|}{y_i}$$

The weights, of course, add up to one

$$\sum_{i=n_o+1} W_i = 1$$

and vary proportionally with the sample size. They can be as extreme as assigning all weight to N, which is a choice that might be made by an analyst who feels that most information is contained in the one prediction made from the largest subsample size. The author's preference for a weighting scheme is

$$(6)\quad W_i = S_i \Big/ \sum_{i=n_o+1}^{N} S_i$$

where S_i is the subsample size used for the particular prediction. This equation would give the predictions from subsample size 10 twice as much weight as the predictions from subsample size 5, and thus is in accordance with the notion that if the estimating procedure is valid, then predictions should improve as the sample size gets larger. Furthermore, the use of this type of weighting scheme does not effectively change the simple interpretation of the summary statistic discussed in equation 4.

Another alternative to average proportional error is that of *squared* average proportional error, i.e.:

$$(7)\quad \text{Squared Average Proportional Error} = \frac{1}{N - n_o} \sum_{i=n_o+1}^{N} (R_i/y_i)^2$$

One would use this type of summarization when he wishes to penalize proportional errors in an exponential fashion.

Finally, one might be more concerned with absolute rather than relative error. A calculation such as

$$(8)\quad \text{Average Squared Error} = \frac{1}{N - n_o} \sum_{1=n_o+1}^{N} (R_i)^2$$

could be made. Although this statistic appears to be similar to the calculation of the variance estimate in regression theory, the residuals in question here are based on predictions, not fits.

A general framework for these summary statistics has been developed in the references in note 1. Not only are different weighting schemes allowed, but one can also define loss functions tailored to the required estimate. For example, overestimates may not be a concern, and the average underestimate may be the appropriate statistic. Also, measures which examine bias, variability, and skewness are presented.

Still the analyst must choose the appropriate summary statistic. But unlike regression analysis, the choice is explicit and can be consistently applied to all candidate estimating procedures.

Statistics Which Depend on a Particular Estimating Procedure

A final set of statistics can be calculated from the historical simulation output by making use of statistical model assumptions that are usually associated with the particular cost-estimating procedure under examination. An example is the multiple linear regression model, which is usually assumed when the cost-estimating procedure of interest comprises a linear EF and a least-squares technique.

From an operational point of view, these statistics which are derived from an assumed statistical model (applicable to an EF) are not very versatile. They can only be used to compare estimating procedures having the same EF and they also depend on the validity of the statistical model assumptions. In contrast, the historical simulation data summarizations presented in the previous section can therefore be used to compare any estimating procedure.

However, the estimating procedure specific statistics are sometimes worth examining. Since they are valid for any estimating procedures which utilize the same statistical assumptions; for example, the class of linear EFs (with least-squares curve fit), they can be used to compare candidate estimating procedures in the class.[5] To date the distribution of the historical simulation output—the predictions and residuals—has been determined for the usual linear regression assumptions. Also, a goodness-of-fit test and a test to determine if there is bias present has been defined for a subset of historical simulation output. These are documented in references cited in footnote 1.

Summary of Historical Simulation Features

Several unique advantages of the historical simulation procedure have been identified. These are summarized below:

—Historical simulation can compare a wider class of cost-estimating procedures than the usual regression techniques.

—Historical simulation provides an easy-to-communicate summary statistic useful for describing the accuracy of a prediction. This summary statistic is average proportional (or absolute) error or one of its weighted forms. It describes how well the cost-estimating procedure would have predicted if it had been used in the past to make predictions of the now historical data.

—Historical simulation provides a view independent of the usual regression theory approach. The candidates cost-estimating procedure is judged on how well it predicts the data from prior data points and not on how well the candidate cost-estimating procedure fits the data as a result.

Historical simulation can be used to evaluate CERs derived from stepwise multiple regression programs. These programs choose the candidate CER which fits the data best (in a least-squares sense). Historical simulation does not depend on this choice criterion and therefore is able to evaluate the CER independently of the stepwise regression choice criterion.

5. These comparisons can also be made with the usual evaluation procedures, i.e., the usual regression statistics and, hence, historical simulation does not offer a comparison that cannot otherwise be made.

Historical simulation gives useful information about extrapolations. Due to its dependence on predicting from past data, historical simulation can demonstrate the estimating procedure's ability to handle extrapolations implicit in the data base. The extrapolation is in the time direction if the data is ordered on time. However, the extrapolation can be based on any dimension of interest as long as the data is ordered in that dimension prior to the historical simulation analysis.

Additional properties include:

—Comparability of selection criteria across all candidate estimating procedures.

—Additional information to help hypothesize a new cost-estimating procedure candidate.

—Exposure of questionable sample points which do not fit in with the prior data base in terms of information content for parameter estimation and in terms of simulated predictions.

—The possibility of uncovering errors in an estimating procedure's formulation which would not be uncovered by the usual regression statistics, Figure 1.

Users of historical simulation are still required to select a definition of accuracy; however, there is value in making this choice explicit (instead of implicit as is often done by *regression theory users*).

But in the final analysis, historical simulation is an additional tool which can give an independent check on the more traditional techniques. As such it should augment and not replace the usual techniques.

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